DEPARTMENT OF DEFENCE
DEFENCE SCIENCE & TECHNOLOGY ORGANISATION **DSTO**

Development of Simulation Services to Support Military Experimentation

Andrew Au, John Best, Peter Clark, Moira Chin, Jennie Clothier, Mike Davies, Richard Davis, Anthony Finn, David Fogg, Anne-Marie Grisogono, Richard Hodge, Rick Nunes-Vaz, Noel Martin, Mather Mason, Simon Oldfield, Helen Pongracic, Peter Ryan, Jason Scholz, Marcel Scholz, Jon Vaughan, Paul Whitbread, Gina Kingston and Cliff White

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Joint collaboration between the Divisions of Electronics and Surveillance Research Laboratory and Aeronautical and Maritime Research Laboratory

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ABSTRACT

One certainty for the future of warfare is change. To be prepared for tomorrow's new challenges, Defence requires organisational flexibility and innovation. A Joint Synthetic Environment (JSE) may facilitate this capacity for change and innovation across Defence. A JSE would link existing and emerging synthetic environments such virtual air, land and maritime platforms; C4ISR, EW and IO simulations developed in DSTO, industry and by our allies through the use of interoperable standards and simulation services based on High Level Architecture (HLA). The extension of the Experimental Command, Control, Communications and Intelligence Technology Environment (EXC3ITE) network to support the use of distributed simulation and military synthetic environments is examined from a corporate research perspective. Issues from operational, systems and technical perspectives are presented, addressing the use of emerging simulation middleware (eg HLA), in harmony with legacy simulation standards. Recommendations are made for progressing the development of simulation services, which will require a response from industry to develop as a National capability to underpin future military experimentation and innovation in Australia.

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DSTO Electronics and Surveillance Research Laboratory
PO Box 1500
Salisbury South Australia 5108

Telephone: (08) 8259 5555
Fax: (08) 8259 6567

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Development of Simulation Services to Support Military Experimentation

Executive Summary

"All organizations must innovate and experiment, or they will lose to competitors who do." (Anon)

"Our capability edge will also come from ***innovative ways*** in which we develop our doctrine, organization and logistics." (Defence White Paper 2000)

One certainty for the future of warfare is change. To be prepared for tomorrow's new challenges, Defence requires organisational flexibility and innovation. A Joint Synthetic Environment (JSE) may facilitate this capacity for change and innovation across Defence. A JSE would link existing and emerging synthetic environments such virtual air, land and maritime platforms; C4ISR, EW and IO simulations developed in DSTO, industry and by our allies through the use of interoperable standards and simulation services based on High Level Architecture (HLA).

We expect that future Defence simulations will be component-based with open interfaces, wrapped by "middleware" (eg such as HLA) to form "simulation services" which are available to any authorized user on the network. This strategy will have significant savings for Defence in terms of cost, evolvability and ease of information management.

These simulation services may be assembled to flexibly integrate synthetic environments as required for specific Defence studies. The knowledge for achieving this resides in the EXC3ITE (Experimental C3I Technical Environment) experience, and we propose to build these simulation services with EXC3ITE information services to facilitate rich military experimentation and innovation.

We examine the use of simulation within DSTO, describe an operational concept and architecture for distributed simulation based on specific "use" cases for various ADF environments, and also address a number of systems and technical issues and potential limitations.

The set of recommendations will be addressed by the DSTO Simulation Hub to progress the development of this capability.

Contents

1. Scope and Vision

One certainty for the future of warfare is change. To be prepared for tomorrow's new challenges, Defence requires organisational flexibility. This involves working in *adhoc* coalitions as a joint force, and exploring innovative ways to conduct operations through the development of new operational concepts, doctrine, processes, and training. A Joint Synthetic Environment (JSE) may facilitate this capacity for change and innovation. A JSE would link existing and emerging environments such as virtual air, land and maritime platforms; C4ISR, EW and IO simulations developed in DSTO, industry and by our allies through the use of interoperable standards.

A modelling and simulation (M&S) strategic plan has been developed[1] which articulates the scope for support to improved capabilities and decision making in Defence. The application areas for simulation pervade all dimensions of Defence activity and are described in depth in Appendix A. They include:

- capability and force structure analysis, including preparedness and resourcing;
- acquisition including systems design, development, prototyping and procurement;
- individual training and collective single service, joint and combined training;
- the conduct of operations, including courses of action analysis, linking strategic, operational and tactical levels of command, mission planning and rehearsal; and
- support to the force in being including development and testing of doctrine and tactics and systems evaluation and improvement.

Many challenges face the modelling and simulation community to realise these application areas. The development of EXC3ITE simulation services means facing the grand challenges of the integration of tools, systems and data; and information management for the *simulation community* as described in Appendix B. These areas are already core to EXC3ITE from its established role in the *C3I community*.

Our vision to drive the *development* of this networked environment is the capability...

"to build distributed simulations in an hour"

To build a complete, and complex simulation in this timeframe implies that an authorised user...

- is able to easily discover, locate and access all necessary data, simulation entities, and tools across the network;
- can construct systems from simple to use, yet rich, interoperable and inter-communicating component entities, data services and tools;
- can change any part of the system as and when required;

[1] "Defence Strategic Plan for the Coordination of Modelling and Simulation", Australian Defence Headquarters, June 1999.

- can be blissfully unaware of the automatically-planned and managed distributed execution on arbitrary hardware and software platforms; where the integrity of order of execution and quality of service of the simulation is assured;
- can rapidly visualise results in any form they wish;
- can reuse, replay, and share any part of the software system they have built; etc...

Computing and communications has the potential to transform the nature of simulation. The use of gigabit data rates is technically feasible now, but is artificially (astronomically) expensive to operate in Australia. When such capabilities are within financial reach of Defence, distributed simulation may operate as if it were centralised. This is an essence of the impact of *"deep computing"* on simulation – a core network of high power computers linked by fibre, providing a new level of *richness* to simulation. At the same time, the growth of *"pervasive computing"* which may run simulations at the periphery of the core network connected through wireless means (eg. on personal digital assistants and other small devices) will present the opportunity to bring simulation closer to the real world. This will have a profound impact on the *reach* of simulation to the level of the individual, with the new opportunity to leverage deep computing and simulation services from the core network.

The purpose of this document is to guide and inform the EXC3ITE project and its users in development of appropriate distributed simulation services to support the DSTO R&D community. It is in response to Takari Executive meeting action 23/2[2].

2. Background

Australia's "Defence Strategic Plan for the Coordination of Modelling and Simulation" was endorsed by the Defence Capability Forum on June 17, 1999. The Strategic Plan includes several key recommendations, of which the most important is the establishment of the Australian Defence Simulation Office (ADSO). ADSO was formally set up within Australian Defence Headquarters in February 2000. A key priority for ADSO will be the promulgation of a Defence Simulation Master Plan, a draft of which was first developed in 1996/97[3]. In addition, ADSO will formulate directives and instructions on key issues such as standards and protocols for the networking of training devices.

The development of information networks heralds a fourth environment for military conflict, augmenting the Air, Land and Sea environments. The Defence Information Environment (DIE) is the Australian Defence information network providing

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[2] ACTION *"Investigate an EXC3ITE simulation service, including architectures for simulation, protocols, latency and bandwidth issues. Working Group to include Jason Scholz, Cliff White, John Best, Jon Vaughan, Mike Davies"*

[3] "Ten Year Australian Defence Simulation Strategy", P.D. Clark, LTCOL, C. Mazur, pp 123- 129, Proceedings of the Third International SimTecT Conference, SimTecT 98, 2-6 March 1998, Adelaide, South Australia, ISBN 0-9585331-0-5.

information to commanders and Defence managers. The DIE incorporates all mobile military elements in addition to headquarters and offices.

The Experimental C3I Technology Environment (EXC3ITE) is a Defence project (JP2061), to develop and leverage the use of middleware in the Defence Information Environment (DIE). Middleware is an emerging technology evolving from current Internet client-server based systems towards next generation Internet multiple component peer-to-peer networks. Middleware provides the interface between telecommunications and user applications. Middleware may be considered in multiple layers. Most significantly for Defence, the "application-oriented" middleware layer consists of components or "information services" may communicate with one another and be assembled as required to effect the required application. With an investment focussed on interoperable information services and components, the need for costly, stove-piped applications is expected to diminish, and the dream of scalable information management will be realised. The benefits to Defence of middleware architectures include evolvability, reuse, scalability, and reliability, and thereby offers significant cost savings to our multi-billion dollar information infrastructure. The architecture for middleware is evolving and is as yet unstable, so EXC3ITE fulfils the role of an experimental network for development, test, evaluation, user requirement elicitation, and user experimentation with middleware information services. EXC3ITE has nodes located in HQAST and AIO, DSTO Salisbury, DSTO Melbourne, and DSTO Fern Hill Canberra, with two mobile, field-deployable units. EXC3ITE offers information services, which include geospatial, track, imagery, visualisation, C3I simulation, enterprise-wide database query, collaboration, and document management. EXC3ITE offers these information services for use by synthetic environments, and along-side other simulated and live systems.

Figure 1 illustrates the role of proposed EXC3ITE information and simulation services in the context of a whole of Defence strategy. That strategy is for an evolving Defence capability built by layers of depth, providing a sustainable competitive advantage, that could not easily be copied by Australia's adversaries. It offers a vehicle for achieving a *common technical framework* between real and simulated systems that embraces data standards, common conceptual models and a high level architecture. Such a framework is essential to the component-based approach to simulation development and assembly.

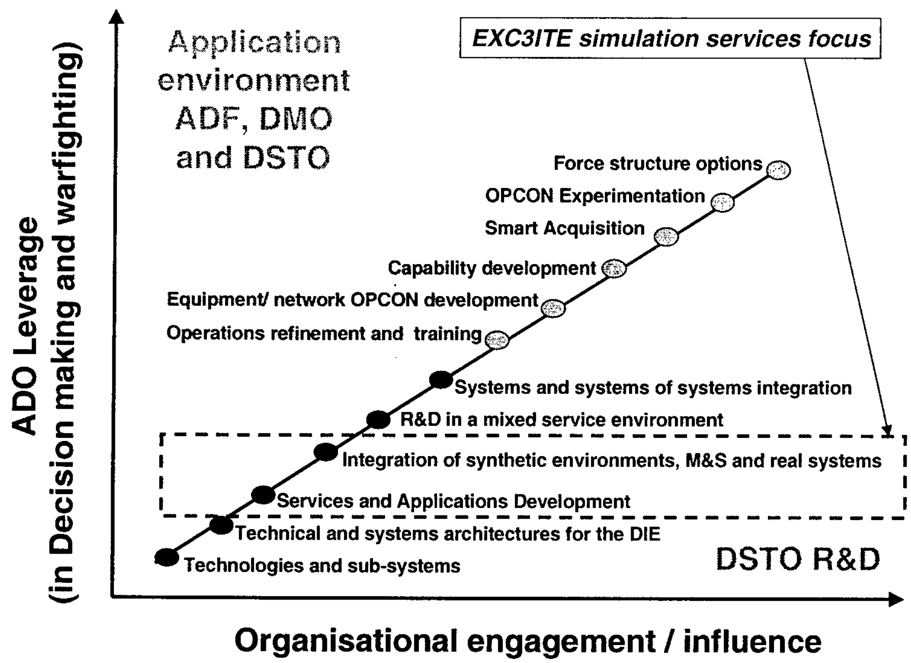

Figure 1. A strategy toward the development of force structure options.

The story of warfare is the story of technology, however, referring to Figure 1, raw technology alone does not make Defence capability. Raw technologies and subsystems generally offer low leverage for Defence, and weak influence on the organisation. The Defence Information Environment (DIE) is an enabling capability to allow information to be harnessed for Defence use. The systems in the DIE provide Defence decision-makers with access to information and knowledge through information services and applications. This level has been the focus of development of EXC3ITE to date. An overlay to this level is the integration of synthetic environments, models and simulations and real systems. This level is the focus of development of EXC3ITE Simulation Services. This facilitates R&D in a mixed service environment (eg. Land-air, Maritime-Air, Joint-Maritime-Air, etc...), forming the basis for innovating. Through the sharing of models, simulations and information new forms of systems (or systems of systems) are expected to emerge. This hierarchy of R&D foundation focuses on DSTO and industry developments, and is the enabler for the hierarchy of military innovation, which follows. Operations refinement and training, equipment and network operational concept development would underpin the development of network-enabled forces. Building on these, capability development and smart acquisition decisions may be supported. Deep innovation through experimentation with operational concepts in turn may deliver Revolution in Military Affairs (RMA) ways for Defence. Lastly, decisions on force structure options at the whole of Defence portfolio level underpinned by the deep experiences of experimentation may facilitate a strong case for achieving Strategic Policy and political ends. All of these areas are relevant to and need to be supported by EXC3ITE simulation services.

Military innovation may be applied throughout the life cycle of a capability, as illustrated in Figure 2. From supporting the development of operational concepts in wargaming through to mission rehearsal, the applicability of such a service may be ubiquitously applied.

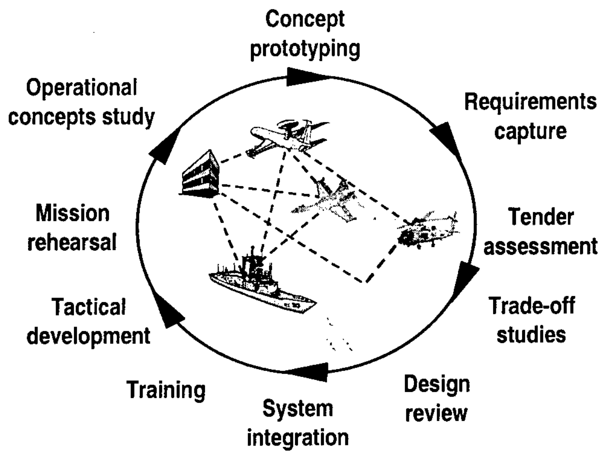

Figure 2. Network-enabled warfare supported by simulation services throughout the life cycle of a capability.

Simulation Related Activities in DSTO

The following diagram illustrates an overview of the current state of synthetic environment and simulation systems development by Division.

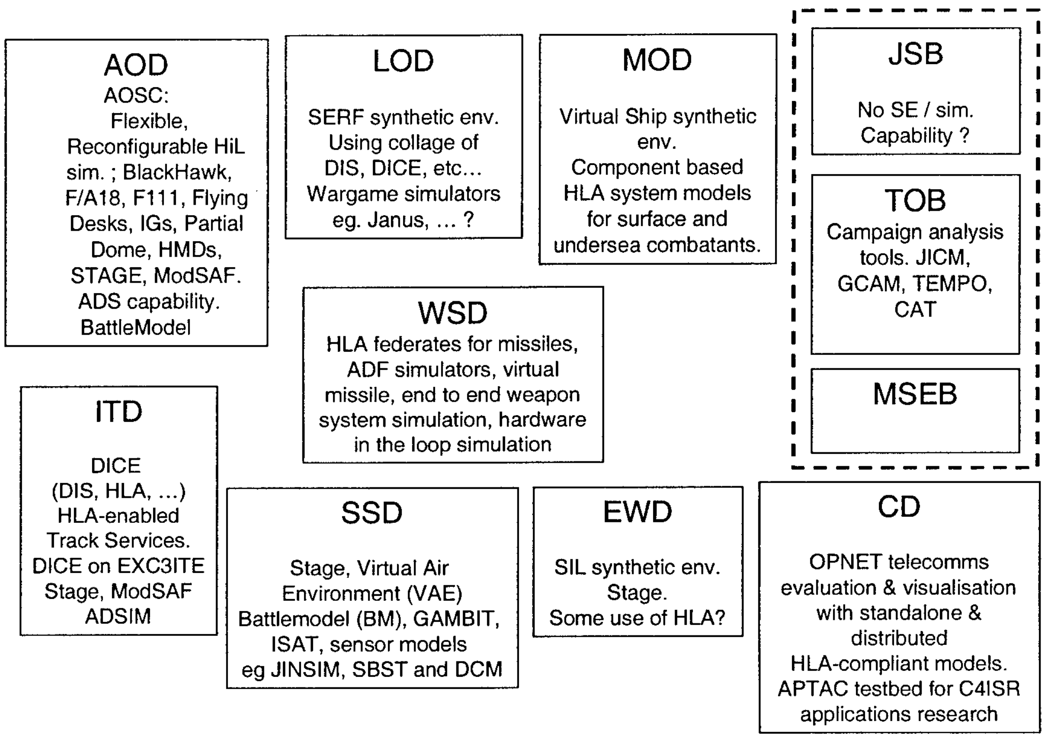

Figure 3: Simulation related activities by DSTO division.

The development of simulations in DSTO has largely been independent at the divisional level. However, each division does have a unique perspective and requirements for their client areas which must be addressed if a single supporting environment is to be pursued.

Air Operations Division (AOD) has an extensive involvement in simulation both in the constructive and virtual areas. The development of AOD's main simulation facility, the AOSC commenced in the early 1990's and achieved initial operational capability (IOC) in 1994. The AOSC is continuing to be developed, particularly in the software area, while at the same time, it is supporting a large and comprehensive experimental program in HiL simulation. Work carried out on the AOSC includes:

- Evaluation of advanced EW warning systems in rotary wing aircraft;
- Determination of safe helicopter operating limits for shipboard landings;
- Investigations of pilotage of rotary wing aircraft using night vision devices;

- Investigations of helmet mounted sights in fast jets; and
- Demonstrations of advanced distributed simulation concepts to support air defence controller training – Virtual Air Environment (VAE) project.

AOD has developed a large range of relationships and interactions with both Australian and overseas laboratories and organisations involved in simulation. These include:

- TTCP JSA TP-2: Modelling and Simulation and AER TP-1: Aerospace Simulation and Operational Analysis;
- US Army, CECOM, Fort Monmouth, NJ through Project Arrangement 10 (EW);
- US Navy, Battle Fleet Tactical Trainer (BFTT) Project on distributed simulation research;
- DGA, France through MOU on HiL simulation with helmet mounted sights;
- US Air Force Research Laboratory (AFRL), Mesa, AZ on distributed mission training;
- US AFRL, Dayton, OH on "Virtual Air Commander";
- Simulation Industry Association of Australian (SIAA) as member of the Executive and involvement in the SimTecT Conferences through the Technical Committee
- RMIT University through support to and collaboration with students involved in postgraduate simulation studies.

The Air Operational Analysis Branch of AOD has major capabilities in constructive simulation. Some of this work is carried out on large simulations models sourced from overseas such as Thunder. However, during the past few years much effort has gone into developing the BattleModel architecture and the BattleModel is currently being employed for a number of operational analysis (OA) studies. Other areas of significant simulation capability within AOD include:

- Advanced Distributed Simulation including DIS and HLA;
- Detailed 6 DoF simulations of fixed wing aircraft, F111, F/A-18, etc;
- Detailed 6 Dof simulations of rotary wing aircraft, BlackHawk, etc; and
- Simulations of stores release from aircraft - studies employing CFD techniques.

Surveillance Systems Division (SSD) subscribes to the philosophy that simulation requires a team of three different types of expertise - domain experts, computer software specialists and simulation specialists. The division is replete with sensor technology experts and a small core of software and simulation specialists interact with them to provide a simulation capability. SSD has recently demonstrated an ability to model integrated surveillance operations at a medium level of fidelity in support of operational assessment studies. It was achieved by exploiting the graphical specification capabilities (visual formalism) of the Simulink and Stateflow simulation tools from the MATLAB stable. These tools allow the physical and information models to be assembled readily, implemented, and quickly adapted to changing requirements if necessary. A formal basis (GAMBIT, Gauss-Markov Bayesian Inference Technique) allowing the use of probabilistic as well as deterministic simulation, and representing information uncertainty within the Integrated Surveillance Assessment Tool (ISAT) has been developed and is being implemented. This is required for simulating surveillance operations where there is a need to model information explicitly. These developments together with the high fidelity simulation capability, Virtual Prototype's STAGE, completes a suite of simulation and analysis tools referred to as the Integrated Surveillance Assessment Tool (ISAT). Cooperation with other Divisions will enable the addition of an open agent infrastructure to STAGE to allow use of a variety of intelligent agents, eg Jack or Attitude, in high fidelity simulations. Completion is expected within two months. The division is committed to providing a range of coarse and detailed surveillance sensor models. A number currently exists eg JIINSIM(OTHR), DCM(IR) and SBST(SAR).

The Information Technology Division (ITD) Joint Synthetic Environment Facility (JOSEF) has a range of capabilities for the construction of C2-led simulation and synthetic environments. The term *C2-led* refers to an emphasis on modelling of and support to C2. The Distributed Interactive C3I Effectiveness (DICE) simulation software suite is a key component of the JOSEF and LOD's SERF and TLCAC facilities and has been installed with SSD to aid surveillance systems assessment. DICE has been released through TTCP JSA TP2 (M&S) in support of collaboration in the interoperability of simulation with real C2 systems. DICE has played a key role in LOD support to 1 Brigade and the CATDC. DICE enables the explicit modelling of orders, reports and requests, simulation of C2 and C2 systems, and facilitates interoperability with real C2 systems through semantic and syntactic equivalence. DICE can employ a library of behavioural models implemented using a range of intelligent agent techniques, interfaces to physical domain simulations such as STAGE and JANUS, and interfaces to operational and prototype command support systems such as BCSS and the Air Asset Visualisation Tool (AVT). Interfaces can employ a range of protocols such as DIS and HLA. The modular composable nature of DICE and its standard internal language has seen it growing as the de facto standard for C2 simulation. DICE has been delivered to EXC3ITE. The JOSEF and its tools are used within ITD to provide M&S support to operational planning and intelligence with key customer engagement of DIO, ASTJIC, HQAST and a vertical slice through operational and tactical Air. Of particular relevance to this report is the engagement with Surveillance and Control Group and simulation and synthetic environment support to air asset and battlespace management.

Theatre Operations Branch (TOB) is developing a technology base in operations research including modelling, simulation, and gaming-based methods, tools and techniques to support Defence HQ and HQAST with analysis and advice. Using gaming as a technique for learning about force structuring depends on being able to explore conventional and innovative operational concepts. Real-time participation of commanders and planning staffs engaged with current or emerging analytical tools over EXC3ITE will significantly improve the range and validity of the judgements that are made about the value of force options across a range of scenarios. In the area of modelling and simulation, TOB has acquired a capability in a number of US tools, including JICM (Joint Integrated Contingency Model) and GCAM (General Campaign Analysis Model). In addition, TOB has developed its own models and development tools, including TEMPO (Theatre Evacuation, Movement, and Peace support Operations tool) and CAT (Campaign Analysis Toolkit). While TOB has a strong capability to produce and carry out analysis based on these and custom built models, the dearth of reusable components and the lack of a deployment infrastructure, has considerably slowed its efforts to give life to these models through visualisation, database persistence and network-deployment. Thus, TOB would benefit greatly from any system that would provide these services and allow TOB to concentrate on core model development skills.

Weapons Systems Division (WSD) possesses a range of simulation capabilities, which include simulations of missile trajectories, weapon system simulations, and mission simulations, which include several weapon systems. WSD has supported the simulation of weapons in for ADF applications such as the F18 and F111 simulators as well as DSTO simulations in AOD, and MOD. WSD has developed a missile-modelling framework, which is being used for missile simulations in the Air Combat Training System. There is a collaborative program with TTCP nations developing a missile modelling interface specification. Work is underway on the development of a virtual missile laboratory which can be used to assess the impact of changes to algorithms and software in a computer in the loop environment which is supported by a suite of analysis, visualisation and validation packages. WSD has a major hardware in the loop capability, which simulates the terminal engagement of semi active and IR guidance systems. A major upgrade is underway to extend this capability by adding infra red scene generation and projection equipment needed to exercise the next generation of imaging infra red seekers.

Communications Division (CD) has established a Communications Simulation Integrated Product Team (IPT) to develop reusable communications models and a framework to promote the rapid construction and analysis of complex, HLA-compliant models of deployed communications systems. The IPT is also supporting the integration of communications models into constructive simulation and virtual environments, starting with the SERF in LOD, and has linkages with working groups developing other synthetic environments in DSTO. The IPT membership currently includes the Army Engineering Agency, CD and LOD but is expected to include representatives from most divisions of DSTO in the medium to long term. The IPT will be expanded in the near future to include Australian industries such as Darenmont, CSC, Adacel, Boeing, DSpace, Compucat and Motorola who have, or are interested in developing OPNET modelling capability. CD is also collaborating with Boeing Australia to develop an OPNET-based System Performance Model (SPM) for the High Frequency Modernisation Project. External collaborations are being set up for exchanges on simulation modelling with the US Joint Staff J6I Network Warfare Simulation (NETWARS) project as well as with industry (eg SAIC) working on the SMARTNETS and SEAMLSS (Global Mobility) projects sponsored by DARPA.

The primary focus of synthetic environment development in Maritime Operations Division (MOD) is the Virtual Ship project. The Virtual Ship concept calls for the integration of simulation models that represent the component systems of a warship. A virtual representation of a warship is thereby constructed in a manner analogous to construction of a real vessel. The primary focus of the program is support of real-time, human-in-the-loop simulation. It is intended to create a controlled environment where humans may interact with warship systems and the effectiveness of the system as a whole may be explored, taking account of the human component. It will support the acquisition and ownership of future generations of naval platforms and enhance the effectiveness of the force in being through its contribution to tactical development, training and mission rehearsal. It is particularly envisaged that Virtual Ship will support Project SEA 4000. In addition, opportunities will be sought to use Virtual Ship to investigate combat system human factors aspects and investigate the role of information in enhancing operational performance, including integration of C4ISR systems. It is anticipated that the Virtual Ship will play a significant role in development of novel warfighting concepts, such as network enabled warfare. The High Level Architecture forms the underlying basis for the Virtual Ship. Each of the simulation components is compliant with the HLA and this facilitates their interoperability and re-use across applications. The Virtual Ship project draws on significant contributions across DSTO divisions and industry. WSD, SSD, EWD and MPD each provide simulation components from within their domain of technical expertise. In addition, a significant number of companies have been engaged in development of the Virtual Ship Architecture, through the mechanism of the Virtual Ship Architecture Working Group (VSAWG).

Other synthetic environment activities being undertaken in MOD include the Virtual Submarine and Virtual Minehunter Coastal. The Virtual Submarine supports the evolution of the Collins combat system via Projects SEA 1439 and SEA 1446. The Virtual Minehunter Coastal (VMHC) supports enhancement of the MHC tactical data handling system. At present these are stand-alone synthetic environments. It is intended to move down a path whereby these interoperate with Virtual Ship components via the HLA. Within MOD a number of stand alone operational analysis simulations are used. These are typically restricted to the above water, underwater and pro-submarine operational domains. The prospect should not be ruled out that these may find use as scenario generators for human-in-the-loop simulation, nor that they may be linked to create scenarios that cross current operational domain boundaries.

ADF Projects and Key DSTO Tasks Related to Simulation

Virtual Air Environment (VAE)

The 1997 Defence White Paper placed a high priority on the ability to integrate surveillance and intelligence information to detect, track and identify all air and maritime targets in Australia's northern approaches. A number of systems (JORN, AEW&C, Air Defence Ground Environment (ADGE), and the Air Command Support Systems (ACSS) are being acquired to meet the air surveillance/airspace control/air defence component of this capability. Introduction of JORN, AEW&C and a modern ground control environment will require a considerable increase in the number of active Air Defence Controllers. However, the number of F/A-18 missions available to support ADCON training will remain static. The significant investment in Air Defence and Airspace Control systems must be supported by comprehensive simulation systems if operators are to maintain an acceptable level of operational capability.

The Virtual Air Environment (VAE) Project aims to provide a framework within which RAAF training simulation activities would take place. The VAE concept would have applicability to a wide range of ADF simulation systems, to the evaluation of operational capabilities, and to the development and analysis of C4I and weapons systems. The VAE concept is based on the stimulation of, and embedded simulation within, the Air Defence and Airspace Command, Control and Communication System (ADAC2S), which will be operational in the year 2001. The VAE could also be linked to Army and Navy simulation systems to provide a common environment for future joint simulation activities.

The Initial Development Phase of the VAE project focuses on an application to Air Defence Controller training, which integrates real assets (RAAF Williamtown Air Defence Controller Consoles) and virtual simulations (comprising Human-in-the-Loop (HiL) and computer generated entities) in one environment, to create a cost-effective virtual world training capability. The vision is to extend the VAE concept to the entire Air Defence System (with similar developments in the Maritime and Land environments). To determine the structure of a mature VAE, an iterative approach of feasibility demonstration and requirements definition is being used. To this end, a series of concept demonstrations are being conducted.

In the first VAE demonstrations[4] the virtual world was generated at DSTO's Air Operations Simulation Centre (AOSC) at Fishermans Bend, Melbourne. The AOSC was connected to RAAF Williamtown via an ISDN Wide Area Network. Virtual entities generated at the AOSC were correctly observed in the RAAF Williamtown radar system. This demonstration involved linking four systems: a human-in-the-loop

[4] Pongracic, H., Zalcman, L., Iob, M., Craven, D., Fulton, J., Fernie, M., Doman, J., Clark, P., Ryan, P., Holland, O., Jobson, S. and A. Robbie. "The Virtual Air Environment: First Demonstration", DSTO Client Report DSTO-CR-0160, July 2000.

F/A-18 flight simulator, two sources of computer generated entities (BattleModel and STAGE), and the operational Phoenix display system for Air Defence Controllers. The first three provide computer-generated entities that stimulate the operational Air Defence System to provide command and control training. An Air Defence Controller, using the real Air Defence System at Williamtown, directed the pilot of the F/A-18 flight simulator in Melbourne to intercept virtual (computer generated) entities also produced in Melbourne. All entities were displayed on the real Air Defence Controllers' display system in Williamtown. Distributed Interactive Simulation (DIS) networking protocols were used. Further demonstrations are planned to stimulate JORN using computer-generated entities, and linking the air and land synthetic environments.

RAN Project SEA 1412: Development of Maritime Warfare Training System

Through Project SEA 1412, the RAN is seeking to develop the Maritime Warfare Training System (MWTS) which will initially link several existing shore-based operations room trainers with a wargaming system to provide enhanced command team and tactical training for the RAN into the 21st century. This system will provide training for the two-ocean based Navy (Sydney and Perth) without requiring expensive collocation of assets. The MWTS would provide manned assets, instructor supervision, and game control and debriefing, for exercises involving both live and simulated assets across a large synthetic operating area.

In later phases of the Project, an Australian wide-area maritime simulation network will be established. This system could include ships alongside at Fleet Base East in Sydney and Fleet Base West in Western Australia, linked via their on-board training systems with the systems at HMAS WATSON. Other ADF simulators, such as RAN helicopter simulators and RAAF P3C, FA-18 and Airborne Early Warning & Control (AEW&C) simulators, may also be able to participate in a common virtual scenario on an opportunity basis.

The approximate timings for these Phasings are:

Phase 2 – 2000 – 2002: HMAS WATSON Simulators - current and approved

- Link shore-based systems for FFG/DDG/ANZAC
- Provide external link - DIS/WAN capability

Phase 3 - 2004+

- 3A: Proof of Concept for link to FFG Ship
- 3B: Establish interoperability with FFGs, Nowra helos; P3C (Edinburgh)
- 3C: Establish interoperability with Submarine trainer, and ANZACs OBTS (Stirling)

Phase 4: Establish interoperability with other ADF systems (2004+?)

Phase 5: Establish interoperability with ships at sea (2010?)

There is potential to extend this environment to include ships at sea, although this requirement will create various communication challenges. Further in the future a

DIS/HLA capability will enable the RAN to participate in international simulated exercises.

SEA 1412 will initially use the IEEE standard Distributed Interactive Simulation (DIS) protocols to link the systems but is expected to migrate to the newer High Level Architecture as this technology matures. A key requirement in migration to HLA is the development of a suitable Federation Object Model (FOM) which describes the data structures for maritime warfare. This may be based on the USN Navy Meta FOM currently under development by the USN Battle Force Tactical Training (BFTT) Project. Other technical challenges entail the distribution of data link and voice communications across both LANs and WANs.

DSTO, through AOD and MOD tasking, has supported development of this Project during the last 6 years, through Concept Development, Feasibility Study, Proposal Evaluation, Tender Evaluation, and Contract Negotiation. Government approval has been granted for Phase 2 of SEA 1412 that entails linking the DDG/FFG trainer with the ANZAC trainer at HMAS Watson in Sydney.

Project Arrangement 10

Project Arrangement (PA10) is a research agreement negotiated between Australia and the United States to conduct collaborative Research and Development in aircraft Electronic Warfare Self Protection (EWSP) systems. Activities to be conducted under PA10 include technology and technique development, modelling and simulation, laboratory demonstrations of integration concepts, and some field demonstrations. The Australian activities are being conducted under Project AIR 5406 - Phase I and Phase II. PA10 consists of ten research and development tasks scheduled to occur over a six year period (begun in 1998), and was designed as a vehicle to meet a requirement identified by the ADF to develop and validate EWSP techniques and assess EWSP technology in support of EW acquisition programs. The assessment of EWSP technology is done to a large extent via the use of modelling and simulation. In the context of Electronic Warfare, modelling and simulation can allow the evaluation under realistic conditions of the performance both of novel EW equipment and countermeasures techniques and also of the EW operators. Task 5 of PA10 aims to develop a capability to conduct human-in-the-loop simulation trials which include high-fidelity models of EWSP equipment. To date HiL simulations incorporating constructive simulation elements have been conducted by linking sites at DSTO Melbourne, DSTO Salisbury and CECOM (US Army) at Fort Monmouth, New Jersey, USA.

3. Simulation Architecture

3.1 Operational Architecture

Operating Concept

The following figure illustrates an operating concept for the Defence distributed Joint Synthetic Environment (JSE). In order to understand the requirements of the distributed simulation system, the full scope of its functionality and types of interaction in its environment are required. The whole environment is driven by plans derived from purposeful questions, experiments, training needs, tests, or other requirements. The Planners develop scenarios, vignettes, specify questions to be addressed and define measures to be instrumented. Two other key domains are shown, the Military Environment and Models & Simulations[5]. The Military Environment may have Real Operations in addition to Participants and Users in/of the M&S capability. Participants and Users utilise a range of systems, including their operational systems, and direct interfaces to the Models and Simulations. The overall capability also includes Assemblers, who compose a total simulation solution from component models and simulations available in repositories. Response Cells & Operators are needed to bridge the gap (media, fidelity, ...) between Participants & Users (eg Response Cells in ADF simulation-based CPX and wargaming), to represent higher control and flank agencies and to enhance the behaviour of simulated entities and systems (eg as in semi-automated forces). Controllers shape the overall environment through injection of stimuli and directives: eg keeping an exercise on track, and making sure key issues are covered. An Audience of Analysts, Umpires, Scrutineers etc observe the conduct of the activity. All people outside of the M&S box are real people.

[5] Note that a 'synthetic environment' embraces the Models & Simulation, Intermediaries & Operators and the various two-way interfaces with the Military Environment. Both the Military Environment and Models & Simulations may be distributed. The concept also works for augmented reality configurations.

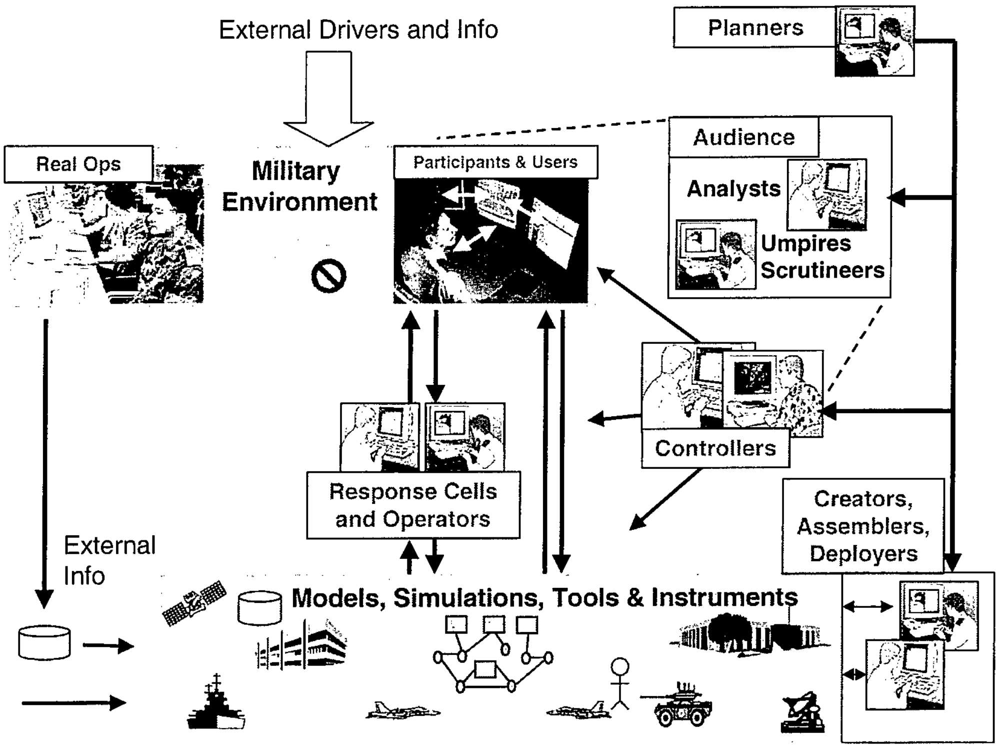

Figure 4: Operating Concept for Simulation Services on EXC3ITE

Interactions can occur within the Military Environment. Real operations may feed data to Participants & Users and shape the simulation world as an "external input". However, any information flow or movement of code from Participants, or Models and Simulations (which includes data repositories) should be barred or carefully managed.

Elements of this most general case disappear or meld with others depending on the specific configuration and purpose. Consider the following examples:

- Training a HQ
  - All elements are largely active
  - A notional opposing force (OPFOR) may be supported by Operators or may be Participants also if this is a training requirement (eg in the case of Exercise PitchBlack)
- Employing simulations for Planning purposes (eg using simple logistic modelling)
  - Real Ops raise a requirement to look at certain issues.
  - EXC3ITE has delivered the capability for military Users to be Assemblers of appropriate models and simulations
  - No Intermediaries and Operators needed

- No Controllers or Audience
- Maybe need to take feeds from real systems as External Input
- Model results inform Real Ops

This framework for simulation is in common with that devised to allow separation of roles in efficiently creating new applications under the Java 2 platform Enterprise Edition (J2EE™) model. A J2EE application (like a simulation) consists of a number of components that maybe derived from separate sources. J2EE specifies three roles, each performing a stage in making an application available for use. These stages aim to separate different skill sets, and different functions within an organisation, from R&D application knowledge, to administration. The roles are:

1. *The Creator* develops a component, by providing an implementation of a defined interface. S/he has knowledge of the business logic of that component, but need have no knowledge of middleware.

2. *The Assembler* takes components, created from various sources, and gathers them into an application.

3. *The Deployer* installs the application on a J2EE platform, and configures and integrates it into the existing infrastructure. This person is concerned with middleware, and is the only one who is concerned with the application transport mechanism - CORBA vs RMI, etc. Most decisions about naming, security and transactions can be postponed to this stage, removing the need for developers in the earlier roles to consider them.

This split-up of roles, and compartmenting of knowledge it implies, works because of the precise specification of the materials passed between stages.

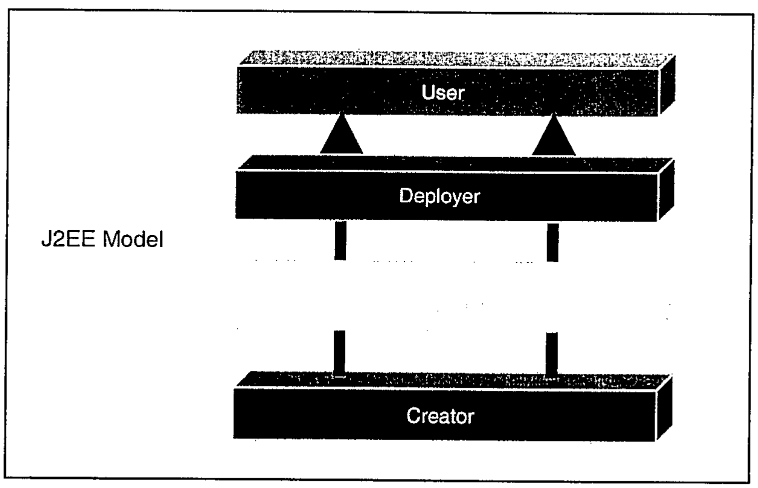

Figure 5: Java enterprise model indicating hierarchy of roles in development of components

3.2 Systems Architecture

3.2.1 EXC3ITE Services

This section discusses the classes (or categories) of service that are provided by EXC3ITE, to prepare for the following section that describes simulation requirements as specialisations of these classes or instances of the classes.

The systems architecture of EXC3ITE is founded on the concept of the use of components to encapsulate intellectual capital, at a level of granularity that allows sharing and re-use to construct C3I applications rapidly and, where possible, under as much control of the user as possible. Whilst the level of granularity is an ongoing research topic, the breakdown presented in this section serves to guide the construction of components at this time and continue to guide thinking for the life of the current phase of EXC3ITE.

EXC3ITE always assumes the underlying foundation of middleware to provide a guaranteed quality of service[6] while hiding details of underlying communications network and the extent of geographical separation of EXC3ITE participants. Services (provided as components) are expected to run as location-independent entities within a distributed system with the potential to be executed remotely to provide a service, and/or fetched from a repository and started up on a convenient machine on the fly.

Components in EXC3ITE are described architecturally, which means that function and interface describe them[7]. Some classes of component form a natural hierarchy, but components are generally designed to allow applications to be formed from a network of peers. For example, applications are likely to be formed from a number of components from the "Value-Add" class with no natural hierarchy.

Some classes described below have instances that support different technologies and are interoperable only through bridges. The EXC3ITE Engineering Management Plan[8], which sets out the guidelines for structure and services on EXC3ITE, intentionally does not specify a particular kind of middleware. Instead it states the intention to support multiple technologies, which include CORBA, DCOM and J2EE as recognised priorities for support in the immediate future.

[6] Quality of Service will be more important to simulation users of EXC3ITE who will need to drive development of this aspect of core services, currently seminal.

[7] IEEE Standard Glossary of Software Engineering Terminology, IEEE Std 610.12 1990, states: "The structure and relationships of components of a system and the rules guide their development and evolution"

[8] EXC3ITE Engineering Management Plan, Report DSTO-TR-1002, AR 001-503, and available online at www.exc3ite.dsto.defence.gov.au

EXC3ITE Technical Reference Guide[9] contains details of the EXC3ITE architecture and currently available services. This description is frozen at the time of publication of this (ESS) document.

Classes of service

Data Repository class

This is the most basic class and refers to "databases" with common interfaces, or databases paired with appropriate data adapters to allow them to join EXC3ITE federations. Most legacy databases with paired adapters (known as wrapped databases) fall in this class. Existing examples of this class are the IMAD libraries, the geospatial SDE server. Future examples include legacy databases paired with MANIFOLD wrappers.

Data Interchange Class

This class contains data adapters which take raw feeds of data and transform them into data objects that are available to other EXC3ITE components. Existing examples of this class are the data feeds derived from message traffic, supplying track data as events. EXC3ITE has a generic data feed adapter that makes creation of a new member of this class straightforward. EXC3ITE has under construction a "publish and subscribe" mechanism, which will fall into this class.

Data Federation Class

Data federation is an important philosophical approach to providing EXC3ITE applications with location and format independent access to data. The main idea is that a federation service mediates in all database access in order to automatically find the database and arrange retrieval by the most appropriate means. There is also a requirement for the federator to provide or facilitate data format conversion. Examples of this class are the IMAD federator and the CDEIS service. It is intended that this class will eventually include agents to track usage of data and relocate it to the most appropriate location to improve quality of service, but this remains a research goal at present.

Core Service Class

This class contains component that expose important functions of the EXC3ITE infrastructure, especially those provided by middleware. This class contains Operating Systems Services, Distributed Computing Services, Network Services and Security Services. Current examples of this class are the trader, directory and naming services (for location of active services on the system), security services (to provide authentication), the transmission availability forecaster (a seminal service to provide Quality of Service), and the starlight data diode. This class includes inter-technology bridges (currently CORBA-DCOM supported in the prototype environment). This class potentially includes tools for collaboration and tools to assist construction of robust applications.

[9] EXC3ITE Technical Reference Guide, www.exc3ite.dsto.defence.gov.au, an online evolving document.

C3I Value-add Class

This class contains many C3I domain specific functions. It is expected that applications will consist of a large number of calls to these services and recursive use of some of these services is possible. This class potentially contains any legacy functionality required by EXC3ITE assemblers through wrapped applications. Existing diverse examples of this class include the track services, DICE services and TBS access service. Intervisibility[10] services, fusion services and 3D visualisations services, all potentially fit into this class.

User Interface Class

The EXC3ITE component philosophy extends to considering user interfaces to be provided by service components, which should enable re-use. Examples of this class are COTS browsers such as Netscape and Explorer, and adaptations of COTS products such as Battlescape/EDGE.

Business Process Class

This class contains the components that are least likely to be re-used. A business process component corresponds to an "application" in that it includes the business logic, the glue for cementing together collections of other components, and particularly the scripting necessary to control the user interface. An example of this class is the proposed eBrief service.

Component Repository Class

This class provides a service to developers, and is analogous to a database containing components rather than data entities. A component repository is store of components, which makes itself available for resource discovery by conforming to a resource discovery protocol. Examples of component repository types are a JINI repository, a RACE component repository, and CORBA component repository. EXC3ITE seeks to limit the number of types of repository in order to make components sharable to the largest number of users possible. However, currently there is no formal limitation, and simulation users may wish to create a simulation specific type of repository.

Instrumentation Class

This class was intended to provide housekeeping functions for the EXC3ITE infrastructure management, but has the potential to be extended to support simulation.

[10] Intervisibility determines the existence of an unoccluded line-of-sight between two points in 3 dimensional space.

3.2.2 Simulation-Specific Services

It is proposed that in order to support simulation, that EXC3ITE support instances of these classes which are delineated as "simulated" as opposed to "real". The most straightforward manifestation would be "simulation" data repositories, but also envisaged are repositories of "simulation" components.

Jon Vaughan and Mike Davies[11] identified four principal categories of service to support simulation, namely:

1. *Repositories of simulation-related materia*l which might include: terrain datasets (for virtual and constructive systems); SEDRIS tools; visual/IR models of entities; executable e.g. flight models; command agents; tools for calculating line-of-sight range and optimum routing; latency and packet-analysers; datasets, for example, platform characteristics; various information and reference sources; lessons learnt etc.
2. *Stimulation services* to be used to feed or *stimulate* a simulation with recorded data. The data origin might be live (tracks, weather, atmospheric/oceanic propagation conditions, sea-state etc.) or simulated (from prior experiments or purpose-generated) with the capability to manipulate the data time base and stimulate at rates appropriate to the purpose.
3. *Immersive synthetic environments* constituting interactive systems of systems, potentially including human-in-the-loop, at fidelities which support appropriate interaction with the system under test, training or study.
4. *Translation services* which might include coordinate converters; DIS to/from HLA; tracks to/from HLA; suitably broad-based or simulation-service-recommended FOMs; RTI Interface Definition (RID) files etc.

These categories map relatively simply to the EXC3ITE classes. Category one maps to the component repository and data repository classes described above. Tools described under this category will be stored in component repositories, but fall into a number of classes such as C3I value add and instrumentation classes.

Stimulation services will be simulation-specific instances of various EXC3ITE classes, and 'immersive synthetic environments' will be a simulation-specific instance of a Business Process class. Examples of translation category map less cleanly into data interchange class and business process classes.

Comparison of the six use cases supplied in the appendices reveals a high degree of overlapping requirements and similarity in structure and function. In terms of the

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[11] Vaughan, J & M. Davies – EXC3ITE Simulation Service: bringing simulation into the operational domain, SimTecT-2000 (28 February – 2 March 2000) Conference Proceedings, pp 39-44.

EXC3ITE classes of service these requirements can be satisfied by services as follows (categorised as instances of the classes):

Data Repository class

Live feeds from real assets: JORN and others.

Stimulation of real systems by simulated data: BCSS, Phoenix

Terrain and environmental services: Australian and regional terrain data sets including elevations, imagery, cultural features, and vegetation data.

Data services which acknowledge the requirement for timeliness of derived data: Trafficability, mobility. (With an ideal infrastructure, these could be generated as required from primary data.)

Data Interchange Class

There will need to be translators of different kinds to support the use cases, but these are implicit, but common requirements have not yet been explicitly developed.. Examples are DIS/HLA translator.

Data Federation Class

SEDRIS services *(SEDRIS supports simulation data for terrain and environment in particular, but is applicable to a much wider set of data types)*

Core Service Class

The requirement for core services in implicit in the Use cases.

C3I Value-add Class

Components to derive geospatial data such as mobility and trafficability.

DICE

User Interface Class

Stealth viewers

Battlemap displays

Business Process Class

Immersive Synthetic Environment Services: Distributed collaborative environments

Component Repository Class

Visual models of platforms:

- Surface ships such as FFG, hostile vessels
- Helicopters such as BlackHawks, Chinooks, ARHs, naval helos
- Fixed wing aircraft such as F/A18, C130, commercial aircraft, hostile air
- Tactical UAVs
- Vehicles such as ASLAV, APC, 4WDs
- Ground elements such as Bde HQ, GBAD, grd based fire support (artillery)

Behavioural models:

Dynamics for constructive renditions of above platforms (currently these are supplied in such simulation environments as ModSAF, JANUS (and BattleModel?) – but the aim would be to have a library of composable models to draw from)

(Dynamics for H-I-L renditions of above platforms are more hardware specific since they must be tightly integrated to the human interfaces, so they would tend to reside in HIL facilities such as AOSC and SERF – there is not currently a strong requirement for an EXC3ITE service of them)

Sensor models – these would span a range of fidelities, broadly classed in two categories:

Those producing detection reports only, and

Those producing simulated sensor data for feeding to human observers and/or data processing and fusion applications.

The sensors required include IRST, ESM, Microwave radar, Fire control radar, GBAD radars, JORN, Visual, Image Intensified (night vision goggles)

C2 models:

such as command agents, Petri nets . . much of the common use case requirement could currently be met by DICE (with suitable modifications) – it is mostly routing of information and commands. More sophisticated agents capable of interpreting and acting on information and commands are under development and could be freestanding or incorporated in DICE too – this needs further consideration.

Communications models

A common requirement is for a comms server to ensure that any message, voice or data link between any two nodes on the battlefield is mediated with the appropriate availability, bandwidth, delay, degradation and so on. This requirement has already been scoped in some detail by Marcel Scholz et al in Comms Div and should be a high priority for development as an EXC3ITE simulation service.

Weapons models:

including ROE and generating appropriate data for targets to compute their own damage by Artillery

ASM and Anti-ASM Missiles

GBAD

Other platform weapons (Hellfire, rockets etc)

Other 'behaviours' such as target marking (eg phosphorus) and designating (laser) – it is not clear yet whether these should be treated as a potential service or remain domain specific.

Environmental effects server for sensor models - requirement has not been articulated yet but is likely to emerge soon.

Instrumentation Class

The goals of instrumentation may be split into two categories, as follows:

1. Warfighting Analysis
   a. Process measures (ie what services used/not used, timeliness of responses etc)
   b. Outcome measures (kills, missiles fired, misses, fuel consumed etc)
2. Simulation System Performance
   a. Performance measures (latency, bottlenecks, loading etc)
   b. Diagnostics (assist diagnosis of problems in eg. Latency, loading etc)

A useful way of characterising instrumentation is using a 3-layer model as follows:

> *User Queries / Reports*. This level represents the goals of instrumentation - what questions are being asked, for which instrumentation data and analysis is required. The requirements could range from being able to replay a given scenario or experiment, to a simple measure of blue/red kills.
>
> *Analysis Services*. This level specifies general and specific analysis facilities required, based on an understanding of the likely questions to be asked, and available data. Services may range from relatively simple statistical packages to more complex visualisation of the filtered data.
>
> *Data*. This level represents the raw and/or pre-processed data, which is recorded by the system or sub-systems. Some automatic pre-processing of data may be required to get the data into a form where it can more readily be analysed. Some of this data may be recorded passively from simulated sensors and services, while other data might be actively requested, depending on the analysis goals.

This class is to include simulation specific tools to:

- compute and display realtime metrics such as performance measures relevant to Situation Awareness (quality, timeliness, availability of relevant info)
- capture SA metrics from relevant players (such as AAR tools, interrogators, etc – this has yet to be defined and developed but is a common requirement)
- capture and display force effectiveness metrics and lower order MoPs such as real-time vulnerability measures, (detectability, identifiability, targetability) etc.

3.2.3 Front-End Issues / Interfaces

The front-end or application-to-simulation interface must provide the user's window into these kinds of services. Even though some requirements are quite simple (a translator, for example, might only need a Javascript calculator or Java applet), if a single interface concept is to provide entry into all simulation services then its capabilities must meet the needs of the most complex 'service'.

One way to proceed is to think in terms of providing four different kinds of portal into these services, categorised in terms of increasing levels of service integration, i.e.,

- Type 1 – does not provide entry into the service, it simply describes the service. It is an information or documentation source, most likely a text web site with links to related sources. For some services, this is all that is required, or all that is feasible to provide.
- Type 2 – again, does not provide a window into or control of the service. It provides a comprehensive help system for using the service. It would provide links to required resources and assistance in their use. It might provide a troubleshooting facility and email contacts to people who can resolve problems. Options for launching smart (wizard-type) assistants might also be present.
- Type 3 – can be described as a 'thin client'. Functionality is delivered by calls from the interface to the underlying distributed services. This is the OpenMap philosophy for use of GeoSpatial Services, and IMAD, for example. Such clients can make use of browser plug-ins to increase capabilities.
- Type 4 – makes no calls to middleware, it provides the service itself. Through an applet, ActiveX component or other means, it provides the functionality required. For example, a relatively simple component might provide line-of-sight assessment on a terrain database, or search and graphical manipulation capabilities on various simulation-related databases.

In most cases it would be preferable to provide more than one of these types in support of a service so that, in addition to providing entry, there would also be comprehensive documentation and guiding and supporting (e.g. troubleshooting) systems.

Under current EXC3ITE way of doing business, documentation in support of types 1 and 2 is kept on line on the EXC3ITE web site, which acts as a primitive portal. Such documentation is a condition of a service being placed in the demonstration environment. There is currently no differentiation between type 3 and type 4 components, although the potential route is to make the stores of these components different instances of component repositories. This requirement is not unique to simulation and will need to be addressed as part of the evolution of EXC3ITE.

The preferred paradigm for the front-end is an area that needs significant research. In simplistic terms it might look like a choice between, on the one-hand, the familiar web browser type interface and, on the other, a dedicated (preferably platform-independent, ie. Java) application. The browser model has much to commend it. It is stable, well tried, well understood, accepted technology with almost zero training overhead. Adopting the browser model would allow us to leverage off the enormous international development efforts continually underway. Applications that have browser interfaces can be exposed to real military users of EXC3ITE via the EXC3ITE/JCSS bridge. Browser technology is also evolvable which would not be the case for a Java application. Mike Sweeney[12] advocates standardising on the browser model (the Browser User-Interface Service, BUS) as a common interface into many of the existing EXC3ITE services.

This model has one significant limitation, however. It can display service outputs (which may be quite complex, eg. 3D objects, or streaming video) but it relies on functionality which is provided by the underlying service. The BUS sends the appropriate messages to the service, then receives and displays its outputs. Since the EXC3ITE philosophy precludes provision of COTS applications, most services on EXC3ITE are and will be written specifically for its environments. Service functionalities can therefore be tailored to interact through a browser front-end as an initial design requirement, so serving through a browser interface presents no problem.

To some extent the same might be said of simulation services for EXC3ITE. Though there are many services that were developed elsewhere and will not be re-written or re-worked, many fall into the repository and translator categories. Systems within these categories, e.g. flight models, SEDRIS tools, packet analysers, coordinate converters etc., can simply be provided (downloaded) to the user to use/launch according to their needs.

At the more complex end of the spectrum of services - supporting distributed immersive synthetic environments - if the interface is intended to provide a controlling, managing facility then the browser paradigm starts to break down. The browser cannot encapsulate the functionality of existing systems, like wargames or HLA federations, and management of multi-functional systems becomes an entirely different issue. This is the problem that LOD's Distributed Study Environment must deal with, having to manage a wide range of COTS, GOTS and legacy systems in a distributed environment. The interface must deal with management on many levels, including bandwidth (so that less important processes cannot deny bandwidth to critical processes), efficient use of distributed processing capability, and local screen real-estate, amongst others. (Ideally for such a complex system, entry to the functionalities should be driven by user-centric principles which dictate that the interface be built, tried and tested first, and the services should then be tailored to fit user demands.) At this stage the nature of an appropriate solution is not clear and needs considerable research. It might help to combine efforts under this project (simulation services for EXC3ITE) and the Distributed Study Environment to resolve some of the issues.

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[12] Sweeney, M, EXC3ITE Browser User-Interface Service, EXC3ITE web site, DSTO Intranet URL: http://exc3ite/pubs/pub_frame.htm

3.2.4 Self-monitoring for corporate knowledge and evaluation

From an early stage in development it is important to build in self-monitoring capabilities to gain feedback on the use of (and nature of use of) simulation services. This information could be used to improve the services themselves, and the interface (front-end) facilitating their use. Capturing such things as common access pathways (to reduce the effort to reach or activate a service if it were many clicks down), should be used to drive user interaction efficiency. There should also be potential (and requests) for explicit user feedback. Services to support simulation-specific requirements would be a natural extension of the EXC3ITE instrumentation class.

3.2.5 Collaboration

Whilst collaboration services have been flagged as an important part of EXC3ITE infrastructure, at this time no instances of collaboration services exist. Collaboration takes on special significance in the context of simulation. Any front-end into EXC3ITE services may wish to include collaboration tools, for example, dropping in a JavaBean to launch a shared whiteboard, or being able to synchronise track views across distributed collaborators. This is a rich area for research.

3.3 Technical Architecture

This section relates specifically to the manner in which the interactive stimulation or synthetic environment services may interoperate and communicate within the larger EXC3ITE environment. It discusses the problems of distributed simulation interoperability from the perspective of the ADF and EXC3ITE and seeks to identify a way forward for allowing interconnection of separate synthetic environments being developed within the ADF and DSTO, including the Land, Air and Maritime environments and numerous EXC3ITE simulation projects. Appendix H provides a background on the Distributed Interactive Simulation (DIS) and High Level Architecture (HLA) standards.

The EXC3ITE network backbone is a high-bandwidth Asynchronous Transfer Mode (ATM) network operating over commercial optical fibre and using military grade encryption. Applications on EXC3ITE operate using TCP/IP connectivity which is routed over the ATM network. Network nodes are assigned as different TCP/IP subnets. Satellite-connected nodes will suffer appreciable (1-2 second) round-trip latency in communicating with other nodes, due to the distance to the geostationary orbits. They will also have less bandwidth available than the land-connected nodes. It is unclear at this stage how the increased latency and reduced bandwidth would effect the efficiency of either the CORBA or DCOM protocols. If significant hand shaking is involved between nodes, then there could be a considerable impact of performance of time critical applications such as real-time interactive simulation.

3.3.1 System Performance Challenges

Quality of Service (QoS)

Network latency is one of the major barriers to large-scale simulations. Resource reservation and multicasting are two important networking capabilities required to support distributed simulations. Resource reservation is able to ensure that different levels of service quality are established across the network supporting distributed simulations. With resource reservation, users are able to reserve a specified amount of bandwidth so those packets may be delivered with the required QoS.

Multicasting

An attempt at overcoming bandwidth limitations has focused on using existing bandwidth more efficiently and reducing the amount of bandwidth demanded by distributed simulations. Multicasting takes advantage of the efficiency obtained when the network can recognise and replicate information packets that are destined to a group of locations. Under these circumstances, the network can take on the job of providing duplicate copies to all destinations, thereby greatly reducing the amount of information flowing into and through the network.

While the HLA does not specify use of a multicasting network, it has similar requirements for many-to-many transmission of object attributes at rates in excess of one update per object per second that cannot be met without multicasting. The network supporting distributed simulations will necessarily be able to support multicasting for various simulated exercises, ranging from tens to hundreds of simulation objects distributed across a number of sites. As the number of distributed objects increases, building multicasting networks potentially supporting thousands of simultaneous multicast groups with large group change rates is a difficult problem.

There is a need to develop multicast protocols that can provide the quality of service needed for distributed simulation, where different types of messages must be transmitted with different degrees of reliability and latency. In the HLA environment, we can identify a number of transmission requirements[13]:

1. low-latency reliable packet delivery, for exchange of occasional data among arbitrary members of multicast groups;
2. reliable point-to-point transmission of control information between individual RTI components;

[13] M. Pullen, M. Myjak, and C. Bouwens, "Limitations of Internet Protocol Suite for Distributed Simulation in the Large Multicast Environment," RFC 2502, IETF, February 1999.

3. best-effort low-latency multicast of object attributes that often change continuously, eg., position of mobile objects;
4. reliable but not necessarily real-time multicast distribution of supporting bulk data such as terrain databases and object enumerations; and
5. low-latency reliable multicast of object attributes that do not change continuously but may change at arbitrary times during the simulation, eg., object appearance.

Area of Interest Management

At a higher level of software architecture, incorporating area-of-interest managers (AOIMs) in multicast routing systems can direct packets of information across a network to particular groups of receivers. The AOIM is simply a layer of software that assigns state changes and entity interactions to particular multicast groups instead of being broadcast to everyone. Such systems allow any member of a group to transmit messages (containing text, voice, video, and imagery) to all other members of the group via a single transmission. Used in conjunction with multicast routing, AOIMs can help minimise the amount of bandwidth needed to support distributed simulations.

This approach prevents the sender from having to transmit individual copies of the message to all intended recipients, freeing resources for other purposes. AOIMs can distribute partitioning algorithms among hosts rather than rely on a central AOIM server. Partitioning schemes can be based on spatial (geographic groupings based on locality), temporal (eg., real-time versus non-real-time), and functional (eg., voice communications, aircraft) characteristics. Research is needed to help define a network software architecture that can properly use AOIMs.

In summary, simulation services require message exchange with different degrees of reliability and latency. Due to the need for real-time multicast protocols with established quality of service, EXC3ITE should provide suitable networking facilities for the anticipated large-scale distributed simulation.

3.3.2 Use of DIS over EXC3ITE

Because DIS is a protocol based standard, rather than a middleware specified standard, such as HLA, it does not conceptually fit well into the EXC3ITE model. DIS applications broadcast PDUs to every node within a subnet rather than follow the application-service provider model that is preferred within EXC3ITE.

An additional problem is that DIS, by default, broadcasts only within a given subnet. As each node of EXC3ITE is assigned a separate subnet, it is problematic to distribute simulations between nodes. This can be overcome by:

- Setting up switches to re-broadcast UDP packets on specific sockets to other subnets. This can be used for specific cases, but is not a scalable solution if we do not know in advance which nodes need to broadcast to which others. Switch reprogramming is not a trivial task and having all nodes broadcast to all others would flood the network with traffic and be very inefficient.

- Setting up specific multicast groups and configuring the simulators to multicast to these groups. Again switch reprogramming is necessary to forward packets between subnets. The solution is more scaleable provided you know in advance which IP addresses constitute the multicast group and can set this up in advance. Adding a new simulator or viewer node which has not previously been designated though would not be possible and you loose one of the major aims of EXC3ITE, to mix and match applications and services.
- Having dynamic IP forwarder processes on the network which can bridge across the subnets and be configured on the fly. The mobile IP technology may provide such a solution. It is unclear what the impact on latency and bandwidth would be except to say that it would suffer higher latency and the forwarding nodes would become bottlenecks to performance as the number of DIS entities increased.

DIS is sufficiently well defined to allow virtual plug and play within the environment, provided the subnet-bridging problem may be overcome. Any DIS compliant application[14] should be able to be connected to the network and immediately be able to take part in the simulation.

Management of multiple DIS exercises operating simultaneously within EXC3ITE may be a problem unless manual methods are adopted to assign a DIS exercise ID (which is unique for each exercise).

For real-time, interactive simulation involving human-in-the-loop models (particularly fast movers), the DIS community had adopted a figure of 100ms as the maximum allowable latency between any simulations. In a typical fast mover simulation, a latency value any higher would result in the human not being able to respond to a stimulus before the action has occurred. For example, he may not see an incoming missile before it hits him. However for other types of simulation a lower latency figure may well be acceptable, particularly for models involving slower moving entities and where there is no human-in-the-loop.

A higher latency is acceptable for applications which simply wish to view the DIS exercise, for example a stealth viewer or an analytical tool collecting data. Because DIS is a broadcast protocol over UDP, with no acknowledgment, it should run acceptably over the high latency satellite links on EXC3ITE, provided that no human-in-the-loop interaction is required. The ideal situation would be to have the constructive modelling taking place within the low-latency fibre based EXC3ITE nodes and to use the satellite node for exercise viewing and analysis (or vice versa). Splitting the

[14] This of course assumes the same version of the DIS standard. There are also issues with fair play, consistency of modelling and consistent terrain databases. However these issues will affect all distributed simulations and are not specific to DIS. It may also be necessary to add DIS enumerations for local entities and weapons.

constructive modelling across a satellite link may still create problems if the entities on one side are required to react quickly to interactions generated from the other node. This problem would not be unique to DIS, but would also occur in HLA.

3.3.3 Use of HLA on EXC3ITE

It is anticipated that large growth in the number of participants will engage simultaneously in distributed simulations. Such an increase in scale in a distributed simulation implies an increase in the size and complexity of virtual worlds. The growth in the number of participants, combined with the increased amount of information that must be exchanged among participants, place additional demands on available bandwidth and computational power. Consequently, distributed simulation is required to operate over a shared wide area network in a scalable manner. In that case, even if the number of hosts varies from a few to thousands, they should be able to interchange state data with sufficient reliability and timeliness to sustain a virtual, visual environment containing large numbers of moving objects.

Real-time simulation requires high-performance systems and low communications latency. Adding more layers of abstraction and protocol for achieving interoperability simply works against the need to meet the latency and performance requirements of distributed simulations. Required accuracy both of latency and of physical simulation varies with the intended purpose but generally must be at least sufficient to satisfy human perception. The HLA only specifies a RTI that is responsible to transmit data reliably, which may choose to do so by various means including redundant transmission using best effort protocols.

At a conceptual level, HLA maps well into the EXC3ITE service based model, with the RTI being used instead of the CORBA protocols (in fact some versions of the RTI were implemented using CORBA). The problems of mapping across IP subnets should be less of an issue, provided some care is taken in configuring the RTI setup. For efficient transfer of information between nodes, HLA relies on multicast groupings being established, which must be detailed in the RID files used by the RTI for configuration. Without carefully optimised RID file, the RTI will still work, although a lot less efficiently that otherwise with appreciable latency and bandwidth overheads.

Overall current implementations of the RTI are benchmarked to be almost as efficient as DIS for small scale federations (few entities) and to exceed DIS performance when large scale federations are involved, using the mapping space filtering provided in HLA. However little information is available on the use of HLA over a high-latency satellite links and it is unclear whether there would be added problems with handshaking across the link. HLA employs two modes of data delivery, best-effort (using UDP multicast groups) and reliable (using TCP point to point transfers). It could be expected that the best-effort traffic would not suffer any penalty over DIS since both employ UDP, but the reliable traffic would suffer appreciable lags, due to the hand-shaking required in the TCP protocol. Federation designers would need to be aware of this detail and take it into account when designing FOMs which specify such information.

Given that there will still be a physical latency introduced on a satellite link, the same conditions on splitting modelling across the link apply as for DIS – where possible, most modelling should be kept to one side of the link, with only viewers and analysis tools on the other end. As mentioned above this problem may be particularly acute when reliable message passing is involved.

Various versions of the RTI exist and most are incompatible with each other. An application compiled for a particular version of the RTI (irrespective of the version of the HLA standard involved) is generally not able to communicate with another application compiled with a different RTI. Thus within the EXC3ITE environment, it would be necessary to standardise which RTI is in use. It would also be necessary to run the RTI executive processes (required by most RTI implementations to keep track of the federates involved) on a set server within the EXC3ITE environment. These processes would require some administration as they need to be present all of the time for any federation to be able to operate – someone must make sure they are always running!

HLA does allow for low-level process monitoring through the built-in Management Object Model (MOM) classes that would permit the EXC3ITE network researchers to examine packet transfer rates and latency.

FOM Interoperability

One of the biggest drawbacks of HLA is the fact that for a federate to join a federation, its SOM must be compatible with the federation's FOM. This means that off-the-shelf compatibility with HLA is unlikely, which contrasts with the situation in DIS. If federate A calls a ship something different to the rest of the federation and in addition represents its location using a different representation, then there is no simple way it can join the exercise. Federation participants must manually resolve any conflict between object models.

To overcome this problem, the US DMSO has specified a number of reference FOMs which constitute standardised FOMs which can be used by a given community. The most notable reference FOM is the Real-time Platform Reference FOM (RPR-FOM) that was designed to cover all the needs of the real-time, interactive simulation community who had previously employed DIS. Looking at the RPR-FOM definition, it is clear that there is a basic mapping of DIS features into the HLA world. ESPDUs are replaced by objects publishing their location and velocity vectors, whilst fire and detonation PDUs are replaced with interaction classes. However the RPR-FOM does provide some degree of HLA plug and play with many commercial applications now supporting the FOM. Caution must be taken though as there have been various versions of the FOM defined as it has matured and later versions are not backwards compatible. Currently, the majority of commercial applications specify the RPR-FOM version 0.7. The EXC3ITE HLA Track Federate, developed as part of the recent HLA/EXC3ITE project, uses Version 1.0 of the RPR-FOM in order to maximise alignment with the EXC3ITE track standard and hence will not operate with Version 0.7. Additionally, the RPR-FOM is US centric and would require some minor additions to represent Australian ORBATs and interests.

The RPR-FOM does provide a limited solution to interoperability, but at the cost of flexibility. If we simply adopt the RPR-FOM, we gain little over DIS. In particular, one of the major deficiencies with DIS is its inability to easily address C2 issues, issues which are significant to EXC3ITE given its C3I enabling qualities and the need for simulation services that provide linkage and interoperate with real world C3I systems. There is a requirement for simulations to be able to explicitly generate and respond to a range of orders, reports and requests. Simulated surveillance assets need to be able to issue detections using appropriate messages that are reported via realistic simulated reporting chains and manifest within real C3I systems[15]. Simulated or real commanders and their agencies must be able to direct simulated assets using appropriate messages that are conveyed via realistic simulated command chains. Standard DIS[16] protocols and the RPR-FOM will not support such interactions; to get down to this level, we need explicit C2 representation within the simulation environment which can be accessed externally. To satisfy this requirement, the recent HLA/EXC3ITE produced an HLA-enabled version of the Distributed Interactive C3I Effectiveness (DICE) simulation. The DICE C2 SOM employs formatted textual messages and their atomic elements to convey orders, reports and requests. DICE SOM libraries can be provided to other federates to enable their use of the SOM. No standardised reference FOM exists for the representation of C2 information, and hence off-the-shelf compatibility is again unlikely.

FOM Bridges

One solution to the problem of incompatible FOMs is the bridge. A FOM bridge is basically a federate that is part of two HLA federations. It can take information from one federation and where appropriate, generate updates and interactions for the second federation.

[15] A focus area under TTCP JSA Group TP2 (Modelling and Simulation) has been established to explore "Simulation-C4ISR Interoperability"; Mike Davies (ITD) is the Australian Focus Officer.

[16] In some packages, such as ModSAF, the range of DIS PDUs has been extended to allow Command & Control Simulation Interface Language (CCSIL) messages, which can be used to send and receive C2 information between simulations. The design rationale of CCSIL was flawed in that the messages were reinventions of real world messaging formats; implementation of CCSIL was limited; funding has since been cut by DMSO.

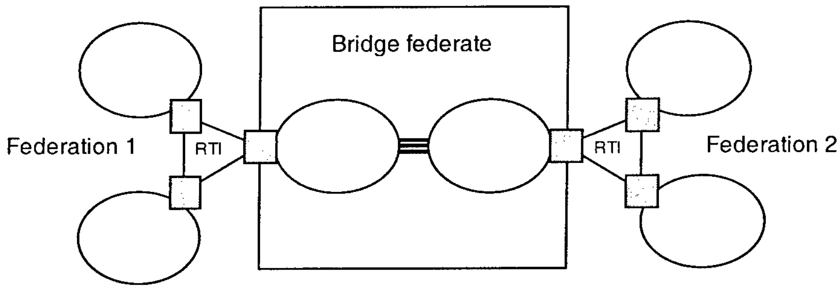

Figure 6: Illustration of FOM bridging

Bridges may also be used for converting from other simulation protocols to a given HLA protocol, for example from DIS to the RPR-FOM, for which many commercial bridges exist. The main drawback with bridges is that they become a bottleneck through which all inter-federation traffic must pass. In addition, as more and more federations are to be bridged, the solution is not scalable, with a unique 1:1 federation bridge required for each pair of federates (unless some intermediary language was used, adding to the bottleneck). Mixing 3 federations would need 3 bridges, 4 federations requiring 6 bridges and 5 needing 10, etc. However if only a couple of FOMs were defined for use within EXC3ITE, then bridges may provide an effective solution to interoperability for limited size exercises.

RTI Hierarchical Federations

A research group at Alenia Marconi Systems in the UK has developed a concept of hierarchical federations (ref) under contract for the DERA in the UK. Hierarchical federations use an adapted RTI to provide similar capabilities to bridging federates, but in a more efficient manner. The new RTI would require information about the two federates it is connected to and would be capable of transferring information where appropriate between them. It would also be possible to allow time management information to be transferred between federations, which could be problematic using a straight bridging approach.

Certainly their description of hierarchical federations may provide a more flexible solution to intra-federation communication that is possible using just bridges.

Agile FOMs

There is some push in the US DMSO to define a specification for Agile FOMs. These are basically a meta-FOM which can describe actual object meanings within the simulation. It is then possible to match the object names and representations used locally within a given simulation with the overall federation FOM, providing a run-time mapping. Using this approach, it should be possible to provide a greater degree of interoperability between federates using different names for similar objects. A problem may still occur however if a different representation is used for a given instance, for example different grid coordinate representation methods.

If the DMSO agile FOM work is standardised, COTS applications will come with a specification of their internal object names and representations, which would be used as input to the DMSO tools to create mappings onto the FOM. The long-term scalability and flexibility offered through this approach is yet to be validated, although it certainly holds promise.

Development of the HLA-enabled version of DICE made use of its standard internal language to arrive at a comparable capability to that of the agile FOM. DICE can accommodate any FOM, without the need for software development, by specifying appropriate mapping data that is used for *run*-time interpretation and creation of C2 messages.

FOM Hierarchies

As an HLA FOM is a hierarchical definition of the objects and interactions within a federation, it is possible to use this hierarchy to provide interoperability between federates for different subsets of the FOM. As an example, the FOM may define a basic entity type with some sort of descriptor field and a location. Below this the FOM may go on to distinguish between land, maritime and air entities. Land entities may then be broken down further into dismounted infantry, tracked vehicles and wheeled vehicles.

For each federate within the federation, it is possible for their individual SOM to only include the information which they are interested in representing. A maritime federate's SOM would include all of the detailed ship modelling, but only represent land vehicles at the Land entity level, ignoring the lower detail.

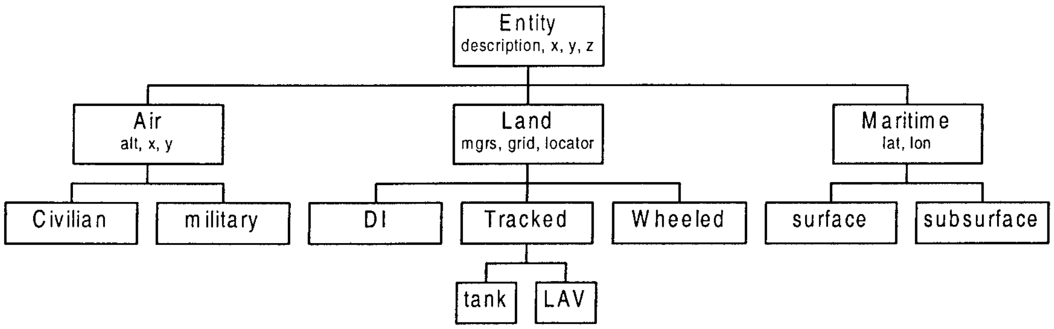

Figure 7: Example model hierarchy.

Using the feature of HLA, we could have individual interest groups define their subset of the FOM and merge these into the final standard. The only condition is that at the higher level, the SOMs must be compatible – the maritime FOM definition group must use the same basic tree structure at the top as the other groups.

Using this approach, it would be possible to define a minimum standard to which all EXC3ITE federates must be able to interoperate. The obvious choice for this would be the (Australianised) RPR-FOM. Below the RPR-FOM we could then define interest area specific hierarchies, for example a whole branch dedicated to C2, another to communications, one to sensor modelling, etc. Provided all groups accept the RPR-FOM as the basic starting point, then at least at the entity level, interoperability is assured. Some suggested interest areas for a FOM working group could be:

- C2 messaging – orders, reports and requests between physical domain simulations and simulated and/or real C3I systems (building on the recent HLA/EXC3ITE project)[17]
- Naval sub-systems, building on the virtual ship
- EW modelling, covering the spectrum of EW capability and the electromagnet spectrums required to model this
- Comms modelling, built around CD's proposed HLA comms models
- Information operations, possibly a subset of the EW
- Sensor modelling, using detailed physics based sensor models

Each working group would design their subset of the overall FOM to be compatible with the other groups, but built from the basic RPR-FOM. The working groups could meet and manage their subset in a similar manner to the Track services working group already within EXC3ITE. However the complexity and management required to facilitate such an approach should not be underestimated, with significant resources required (in terms of time) for the development of a complete FOM.

[17] A collaborative program of work has been established between ITD and Boeing Australia to explore the significance of HLA to C2. The collaboration will bring together DICE HLA capabilities and the *meta-FOM* (or object model atoms) capabilities of the Boeing Australia Synthetic Environment (BASE).

3.3.4 Networked Game Consoles

Beside the standard-based future of HLA, which is largely US DOD driven, alternatives exist for distributed simulation. The entertainment industry, and the computer games industry in particular is producing sophisticated simulation systems based on very powerful computer architectures with advanced visualisation, and integrated network data exchange capabilities[18]. These games already are available with development environments, to allow enthusiasts to develop their own entities / components and stories / scenarios. This allows the manufacturers to gain an increased market share by leveraging off free talent, who provide increased functionality of their products. Similarly, for DSTO, if the cost of software reuse proves too high, networked games platforms running custom-developed code poses a potentially very low cost alternative to a heavy standards-based approach.

The fortunes of the games industry, more than any other entertainment media, are inextricably linked to the development of new hardware platforms. Every new console machine launched has a typical lifecycle of four or five years before it is superseded by a new generation of more powerful platforms.

4. Recommendations

Structure, Process and Next Steps

- This paper be treated as a living document, with responsibility for further development handed over to a focus area under the management of the DSTO Simulation hub.

- As part of the focus area, establish an EXC3ITE Simulation Services Working Group (ESSWG) to oversee development of the EXC3ITE Simulation Architecture (ESA). The ESSWG will be a joint DSTO-Industry forum formed explicitly for this purpose. Mechanisms for industry involvement in the ESSWG can evolve with guidance from the recently formed Defence Simulation Advisory Forum (DSAF) chaired by the Director-General, Simulation (DGSIM) in ADHQ. The President of the Simulation Industry Association of Australia (SIAA) is also a member of the DSAF. The ESSWG will endorse a broad statement of requirement for the ESA and shall call for proposals for components of it. Proposals shall be based on existing solutions, or proposed solutions that can be readily implemented to prove underlying concepts. The ESSWG will endorse proposals for components of the ESA. The operation of the ESSWG shall be governed by Terms of Reference drawn directly from the model of the Virtual Ship Architecture Working Group terms of reference (Appendix I).

[18] See the report "Modeling and Simulation – Linking Entertainment and Defense" 1997, Online at: http://bob.nap.edu/readingroom/books/modeling/

- Based on the aggregated information from the "use cases", the ESSWG develop a priority list of services for development. The priority services should be further scoped and costed for EXC3ITE funding well prior to the end of FY00/01.

- RLMIE accept responsibility to develop a second phase of EXC3ITE (proposal for FY01/02), incorporating the development of enduring simulation services. This proposal be shaped by the focus area, recommendations by the ESSWG, the Defence Simulation Advisory Forum (DSAF) and the test and evaluation community (eg DTRIALS).

Technical Issues for Further Investigation

- Based on practical experience of simulation to limit the scope of activity, the ESSWG develop and evolve an architecture for **secure interaction between real and simulated** information and infrastructure.

- Endorse the use of HLA and DIS with an EXC3ITE administered DIS-HLA bridge being provided for interoperability between the two environments, and pursue the development of a **DIS-HLA bridge** as a priority.

- The simulation hub continue to **monitor and assess the capabilities of simulations developed by the entertainment industry**, as a viable contender to the heavily standards-based approaches of HLA and DIS.

- EXC3ITE will provide **QOS managed services** for both HLA and DIS simulations.

- HLA FOM interoperability be addressed by a FOM working group in the focus area to **define the top-level Australian FOM**, based around the RPR-FOM if found suitable. A number of application area working groups can then begin to tailor their specific FOM subsets for incorporation into the overall EXC3ITE endorsed FOM. This be backed up by publishing and promulgating the base FOM throughout DSTO and the EXC3ITE community.

- It be recognised that certain areas may decide that the chosen, RPR-FOM based FOM is not applicable or suitable for their interests. Such areas may include those undertaking detailed engineering simulations or non-entity based modelling. **Simulations that hold a clear case for non-interoperability with EXC3ITE federations should meet no impediment to developing their own FOM.** They may still wish to utilise the remainder of the (simulation) services on EXC3ITE and so support should still be provided for their use.

- **DSTO Chiefs** demonstrate their understanding of the significance of the level of effort required to develop these services, and **provide the level of commitment (priority and resources)** to pursue the work.

Appendix A: The Vision for Simulation in Defence

Introduction

The Australian Defence Organisation (ADO) will use simulation to enhance Australian Defence Force (ADF) capabilities, save resources and reduce risk.

The fundamental process from which such benefits emerge can be described simply as the gaining and sustaining of knowledge by the use of simulation.

Defence will look increasingly to simulation to take better account of the complexity, the dynamics and the uncertainties that pervade modern warfare.

Areas of Use and Benefit

Simulation will provide a readily available, flexible and cost-effective means to enhance ADF capabilities in the areas of defence analysis and planning, research and development, force development, acquisition, training and support to real operations.

Simulation facilities will provide realistic representations of activities in warfare, crisis management and peace support operations. These will include interactions with civilian organisations and authorities as required.

Simulation approaches will enable Defence to plan its operations and its investments more wisely.

Simulation will allow ADF personnel to train in their normal working environment and to interact realistically with other staff - or with simulations of other staff. The connection of simulations to existing and future ADF Command Support Systems will be routine.

Live exercises will be enriched by (and in some cases replaced by) simulations to improve realism, allow operations to be experienced that are otherwise impractical to conduct in peacetime, reduce the cost of training and reduce adverse impacts on the natural environment.

Simulation approaches will provide representations of the real world to stimulate evolutionary improvements in almost all aspects of ADF operations. They will facilitate analyses of complex decisions facing Defence leaders and improve the mission readiness of Australia's forces.

Simulation facilities will be able to integrate a mix of computer simulations, actual war fighting systems and military system simulators. Components of that mix may well be geographically distributed. The resulting capabilities will allow detailed exploration of simulated missions and related key aspects of operational environments.

Technical challenges will be met so that reusable simulation components can work with others to offer the maximum capability, flexibility and cost-effectiveness. This will become possible as Defence adopts the necessary technical standards being developed in concert with Australia's international partners.

Simulation will continue to provide a powerful tool to support research (including studies and analyses) and to develop Defence technology. Such simulation capabilities will also find productive use in support to the acquisition process.

Representations of proposed systems within simulated operational environments will support phases of the acquisition process from requirements determination and initial concept exploration to the manufacture, test and evaluation of new systems.

Early operational assessments via simulation of new systems and system upgrades will be examined for their operational and logistical impact prior to investment decision. As a result, military system requirements may well be advantageously refined. Cost and operational effectiveness assessments will be rendered more credible and persuasive.

Assessment via simulation will improve the quality of information available to influence resource allocation decisions. Continuing evaluations in the relevant simulated operational environments during system development will improve engineering trade-off analyses and ensure that the final product best satisfies ADF needs.

Simulation will enable tests, evaluations and analyses otherwise infeasible because of limited test resources, environmental restrictions or safety constraints.

Simulation will enhance the sharing of information among designers, manufacturers, logisticians, testers and users. Increased dialogue among these groups will promote more effective interaction between the operational and acquisition communities.

Key Drivers

This vision will be achieved via a Defence-wide co-operative effort that ensures affordable simulation development, interoperability and reusability. The necessary effort and its results will therefore have the following attributes:

a. Funding will be coordinated centrally when appropriate and distributed across the relevant Defence stakeholder communities;

b. Military personnel will interact with simulated mission activities in the same way they interact with the real world by using operational systems with which they are familiar;

c. Developments will allow the linking of self-contained simulations, human-in-the-loop simulators and personnel using real-world equipment as appropriate for user purposes;

d. Simulation systems will be interoperable and reusable to the maximum practical extent;

e. Enduring technical standards will emerge that allow ready composition of diverse simulated activities to satisfy the broad range of existing and emerging needs;

f. Work on simulation approaches will develop and combine the use of the capabilities of government, local industry and academia;

- Simulation facilities will be provided by using existing government off-the-shelf and commercial off-the-shelf software and hardware. Modification of these items or the building of new items will only take place where required and cost-effective;

g. Simulations will be verified, validated and accredited for their intended purpose;

h. Simulation systems will accommodate where necessary the security needs of the Defence Information Environment;

i. Activities will secure mutual benefits from fostering co-operation with Australia's traditional and non-traditional allies;

Key Requirements

Integrated high-level simulated mission spaces that support the ADF in the principal application areas of defence planning, training, exercises and support to operations;

Standard tools and services to support employment of the principal applications;

A capability to operate seamlessly with existing and planned ADF operational CIS such that the simulation is transparent to users;

Interoperability with allied simulation systems to support the training of multi-national forces for coalition operations;

A reduced requirement for directing staff and response cells by providing an automated representation of friendly and opposing force actions, as well as the response of the operational command structure;

A capability to conduct comprehensive post-exercise analyses that can reconstruct events and derive lessons for users in real-world operations;

Representation of the highest priority land masses, hydrographic regions, the atmosphere, space and weather, along with application programs to access and manipulate the databases;

A database of representative fixed installations, generic enemy order-of-battle (OOB), actual friendly forces OOB and realistic weapon system attributes.

Appendix B: Challenges facing the Modelling and Simulation community

Introduction

A key reminder emerging in 1999 from deliberations by the US National Research Council ran as follows:

"History is littered with plans, both strategic and tactical, that were conceptually brilliant, but failed because the barriers to success were not carefully considered."

With this cautionary note in mind, what does need to be identified for careful consideration before the full potential of modelling and simulation in Defence can be realised?

The potential barriers to success are recognised as challenges in the following three related domains:

- Challenges with Culture, Management, and Economics;
- Challenges with Information Management;
- Challenges with the Integration of Tools, Systems, and Data.

The sections below summarise these challenges.:

Challenges with Culture, Management, and Economics

a. Difficulty justifying strong corporate commitment to implementing collaborative technologies because of their complexity and uncertainties regarding costs, metrics, and benefits;

b. How do you encourage the necessary collaboration across organizational boundaries?

c. Unknowns concerning the total costs of implementing collaborative technologies and systems and the return on investment. Resource savings are a motivator;

d. High initial and maintenance costs of new collaborative technologies and systems in a cost constrained environment;

e. Risk - someone has to assume the risk – once identified, how is this to be shared between Defence and Industry? Risk reduction is a motivator.

f. Planning and timing issues - when to bring in the new and retire the old?

g. Difficulty managing constant change as vendors continually upgrade tools and other technologies;

h. Client acceptance – the substantial challenges for the Modelling and Simulation arena represented by Verification, Validation and Accreditation responsibilities;

i. Human Factors aspects - how does an organisation overcome its culture/practices barriers to avoid technology being ineffective through misuse or non-use.?

Challenges with Information Management

a. Difficult to maintain configuration management for product designs, processes, and resources;

b. Need to provide system agility so different users can easily input, extract, understand, move, change, and store data using familiar formats and terminology;

c. Difficulty upgrading internal infrastructures to support large bandwidths associated with sharing of data and information;

d. Need to provide system security and to protect proprietary data without degrading system efficiency.

Challenges with the Integration of Tools, Systems, and Data

a. Lack of tool interoperability-- proliferation of tools aggravates interoperability issues;

b. Existing investments in legacy systems and difficulty integrating legacy systems with newer advanced tools;

c. Little effort by software vendors to address interoperability/data exchange outside of their own suite of tools;

d. Multiple hardware platform issues - computers, hardware, databases, and operating systems;

e. Lack of formal or informal standards for interfaces, files, and data terminology;

f. Standards that will free companies to innovate much more rapidly, and profitably than is possible with proprietary approaches to encourage focus on high-value capabilities without having to rewrite the architecture or interface;

g. Increasing complexity of tools calling for a collaborative environment capability;

h. Difficulty of inserting emerging and advanced technologies, tools, and processes into current product and service environments;

i. Supplier integration issues;

Appendix C: Utility of Simulations and Synthetic Environments to Strategic and Operational-level Issues

Modelling and simulation can significantly enhance operational planning and command decision making at the strategic and operational levels. EXC3ITE has a key role through initial concept and capability demonstration and experimentation, plus a capability enabling operational 'reach' into DSTO and possibly industry. An integrated modelling environment (In-MODE) is essential here, ie one that enables staff to work at their appropriate level but with the ability to explore issues of detail by navigating up and down a spectrum of models and simulations as required. Simulations and synthetic environments of the nature largely considered for 'EXC3ITE simulation services' therefore have utility in operational planning and command decision making at the strategic and operational levels but within the In-MODE spectrum. The spectrum would need to integrate a range of causal, temporal and spatial models in order to enable:

- Modelling and analysis of indicators and warnings, Pol-Mil-Soc-Econ sensitivities and other issues; sensitivities to transactions of national power;
- Support to the architecting through to rehearsal of operational plans;
- Effects-based analysis through influence-effect-consequence and constraint modelling;
- The integration of target systems analysis models;
- Temporal and spatial issues of courses of action (COA);
- The early pruning of unwarranted courses of action through tools that enable the mapping of critical vulnerabilities through to centres of gravity;
- The ability to employ detailed models of logistics, attrition and weapon and platform performance as required;
- Simulated COA execution in time and space;
- Interactive 'Blue against Red' wargaming and rehearsal of selected COA;
- Strong cross-population of models such that simple models permit focussed use of 'expensive' detailed models and simulations and detailed models provide shaping factors for simple models; and
- Integration with operational and other databases to minimise duplication of data entry.

General example:
The following example is rather sequential in nature; in reality there would be numerous iterations and cycles that employ the various models and simulations and engage multiple levels of the ADO.

Routine:
Interactive Bayesian influence networks (**I&W models**) of regional Pol-Mil-Soc-Econ situations have been constructed by strategic intelligence analysts and maintained routinely and **collaboratively** through input from **geographically distributed** analysts from the operational and tactical levels taking feeds from various intelligence and other sources. The models capture the **causal** relationships between possible direct or indirect influences, key hypotheses of interest such as Decline in Foreign Government Control and associated threat to Australia or Australian nationals. The models have been updated based on observables. The models provide powerful components of strategic Indicators & Warnings (I&W) capability. The models capture a subjective assessment aided through reference to detailed econometric, cultural and other models. The I&W models have been routinely used for instability prediction and to determine, observe and analyse sensitivities and pressure points and to advise Government on issues concerning diplomatic influences.

Also developed routinely, drawing on intelligence sources and domain expertise from strategic intelligence and Theatre components, is a suite of dynamic target systems analysis models (**TSA models**). The models are maintained routinely through prioritised intelligence collection and integration with dynamic intelligence databases and are accredited intelligence products. The models consider a potential 'enemy as a system', help manage and analyse intelligence gaps, and embrace system dependencies, behaviour in **time and space**, flows, processes, performance, recovery, criticalities and vulnerabilities. The system models make reference to **detailed models of platform performance, weapons, sensors and natural environment**.

Increasing tension:
A prediction of increased turmoil in particular areas of the region results in the issuing of a warning order and military strategic estimate to the Theatre that triggers off deliberate through to immediate planning. The I&W models are part of the warning order package and give an increased awareness to theatre planners of the associated strategic issues. The I&W models are **updated** as events occur and national and international political and other non-military influences made. Operationally focussed, lower-level but integrated I&W models are developed and maintained by the operational intelligence staff.

COMAST defines constraints and military end state (the *why* of COA) in terms of adversarial centres of gravity (CoG, eg force projection). A **quantified causal** model is built that describes friendly and adversarial CoG and their dependency on critical vulnerabilities (CV, eg communications, POL supply points, ...) taking into account cultural and other factors. The TSA models are now employed by the operational intelligence staff within the context of commander's intent, constraints, military end-state and strategic objectives to aid the mapping of CV to CoG, determine validity of targets and focus intelligence collection. Pruning of unwarranted COA can occur in terms of target CV through analysis of task and weapon options, strategic Pol-Mil sensitivities and relative causal effect of CV influences on CoG. Risk and cost also eliminate consideration of certain options through awareness of own vulnerabilities that need to be protected and minimised. An initial list of candidate hard and soft target CV plus task options evolves (the *what* and *how* of COA).

Discrete event dynamic system models are built of remaining candidate COA branches and sequels that enable assessment of scheduling, deconfliction and resourcing (the *when* and *with what/whom* of COA). The results from execution of detailed models of own force logistics, information networks, sensors, platforms, and weapons are generated and considered in timings and probabilities. **Likelihood and temporal** analysis, eg of logistics feasibility, further prune the candidate COA space. The TSA models are used to highlight restricted and protected targets and to explore the significance/criticality of intelligence gaps to candidate COA. The models enable an assessment of likelihood of detection, response and attribution. A modified target list plus scheduled and resourced candidate COA evolves.

A distributed simulation is quickly assembled using interoperable models of relevant sensors, platforms, weapons, information networks and C2 that enables particular COA to be constructed and executed in **time and space** (the *where* element). R&D models are drawn from DSTO as required. Analysts access detailed radar and platform performance models to satisfy non-Janes type queries regarding the natural environment and associated geospatial issues. The candidate COA space is narrowed further.

Particular COA are **wargamed** by planning and intelligence staff using a range of techniques including a **distributed C2-led synthetic environment** that supports interactive experimentation by 'Blue and Red' planners. The synthetic environment is rapidly constructed using components from earlier and/or others of increased fidelity. The wargamers are able to trial opposing COA in order to test robustness and fine tune the COA. Staff are employed as response cells and operators that act as intermediaries where necessary between the wargamers and the simulations to ensure the necessary richness to the overall environment. C2 simulations are employed in order to ensure awareness of and experimentation with C2 issues.

The various models and simulations with rich visualisations are used to impart the recommended COA(s) to COMAST who decides on the appropriate action. Alert orders and operational instructions are raised and prioritised target lists drafted. Simulations are constructed that support initial and detailed weaponeering, force application planning and trade offs.

Rehearsal:
A distributed synthetic environment employing a mix of interoperable virtual and constructive components is rapidly assembled with scientific support and enables the key component HQs and lower-level agencies to rehearse the chosen COA. The overall configuration includes a combination of the real C2 system plus simulations of systems

and networks yet to be deployed. The rehearsal highlights various issues concerning execution and results in lower-level refinement and increased preparedness. Again, an opposing force is represented.

Execution, situation awareness and battle damage assessment:
The COA is executed; supported by findings from influence modelling, the military actions are coupled with diplomatic in order to increase likelihood of achieving desired effect. The TSA and updated I&W models aid situation awareness by helping an understanding of the rationale, nature and significance of prior, current and possible future adversary actions. Imagery and other intelligence is used in the assessment of physical and functional battle damage; the TSA models are used in the assessment of overall systems impact and aid formulation of re-attack recommendations. The CV to CoG models are used to dynamically gauge impact on CoG.

Appendix D: Joint Architecture "Use" Case

Description

The purpose of this environment is to facilitate the study of the joint awareness capabilities of the elements of an operational scenario.

During an operation, various ADF elements work together in groups to achieve mission objectives within varying time and space parameters. In terms of situation awareness, simulations to date have concentrated on either a platform perspective, or a headquarters perspective and have focussed on either measures of performance outcomes or decision making issues.

This application aims to provide an environment within which information contributions from air, land and sea elements, as well as from joint strategic assets, are examined for their relative impacts on joint situation awareness. Joint situation awareness, in this case will include how each of the elements contributes to:

- its own situation awareness;
- the situation awareness of the other elements with which it is operating to achieve particular mission objectives and
- mission outcomes.

This environment would seek to model the information aspects of each of the entities – the information that each element can acquire, process and disseminate to the other elements of the task group.

The elements of the scenario have been chosen to utilise and extend existing simulations, and the knowledge gained through them of the platforms' Operating Concepts and capabilities.

Example Scenario

This scenario is named *Enforcement of a Territorial Exclusion Zone.*

A single Warship is enforcing an exclusion zone in the waters around an Australian Territory with a helicopter capability onboard. This exclusion zone is protecting an Australian surveillance base on Australian soil which consists of an Army HQ and a Ground Based Air Defence System.

An AEW&C aircraft is operating in the area. The AEW&C is undertaking surveillance and control tasks in the exclusion zone.

Also operating in the area is an F/A 18 fighter aircraft, under the tactical control of the AEW&C.

During the scenario, there will be an enemy incursion into protected airspace.

Also during the scenario, an unknown vessel will be detected within the exclusion zone and close to the Australian shore.

When the AEW&C or GBAD detect the aircraft, they will make the information available to all other participants capable of receiving it.

When the AEW&C or FFG detect the vessel, they will make the information available to all other participants capable of receiving it.

Outcomes

One outcome of this simulation will be to establish the relative strengths and weaknesses of the situation awareness states of each of the entities at various points during the scenario.

Another outcome will be an assessment of how effectively the joint task group can detect, identify, and respond to the enemy aircraft and vessel.

Entities

The entities within this scenario can be classified as detection or response entities.

The *Detection* entities are:

- Warship
- AEW&C
- Army HQ
- GBAD system

The *Response* entities are:

- F/A 18
- Helicopter
- GBAD

Intrinsic Behaviours

Table D-1: Intrinsic behaviours.

Entity	Behaviour	Inputs (description, rate, fidelity)	Outputs (description, rate, fidelity)	Fidelity
Detection				
Warship	Detects vessels, Intercepts vessels	Radar signal, Message, Voice	Own position, Detections, Tracks, Status Data (Message, Voice)	Med
AEW&C	Detects vessels, Detects aircraft, Controls friendly aircraft and vessels	Radar signal, Message,	Own position, Detections, Tracks, Status Data, Commands (Message, Voice)	High
Army HQ	Commands and controls the GBAD	Track	Commands	High
GBAD system	Detects aircraft	Radar signal	Detections, Tracks (Voice, Message)	Med
Response				
F/A 18	Intercepts vessels, Intercepts aircraft	Voice, Message?, Radar Signal	Status Data (Voice)	Low
Helicopter	Intercepts vessels	Voice, Message?, Radar signal	Own position, Detections, Tracks, Status Data (Voice, Message?)	High
GBAD system	Intercepts aircraft	Radar signal	Detections, Tracks (Voice, Message)	Med

Static Relationships

Table D-2 Static Relationships

High Level Entity	Is composed of low level entities

Interactions

Table D-3 Interactions.

Initiating entity	Interaction	Receiving entity
Warship	Deploys	Helicopter
Warship	Sends Message, Tracks	Helicopter, AEW&C, GBAD, Army HQ
AEW&C	Commands	F/A 18
AEW&C	Sends Message, Tracks	F/A 18, Helicopter, GBAD,Warship, Army HQ
Helicopter	Sends message	Warship, AEW&C
Army HQ	Commands	GBAD
GBAD	Sends message, Tracks	Army HQ, AEW&C, F/A 18, Warship

Scenario Execution

Tasks

The Warship operates detection devices.
The AEW&C operates detection devices.
The GBAD operates detection devices.
The enemy aircraft enters protected airspace.
The enemy vessel appears in restricted waters.
Information is exchanged between interacting entities.
Time slices of relative situation awareness for each entity is captured.
Command and control of the response entities is (to be decided).

Initial conditions

The warship is located at a given position, with a given speed and course.
The helicopter is attached to the warship.
The F/A 18 is located at a given position, with a given speed and course.
The GBAD is located at a fixed position.
The AEW&C is located at a given position, with a given speed and course.

Termination conditions

Enemy aircraft is identified and intercepted.
Enemy vessel is identified and intercepted.
Enemy aircraft reaches Australian shoreline.
Enemy vessel reaches Australian shoreline.

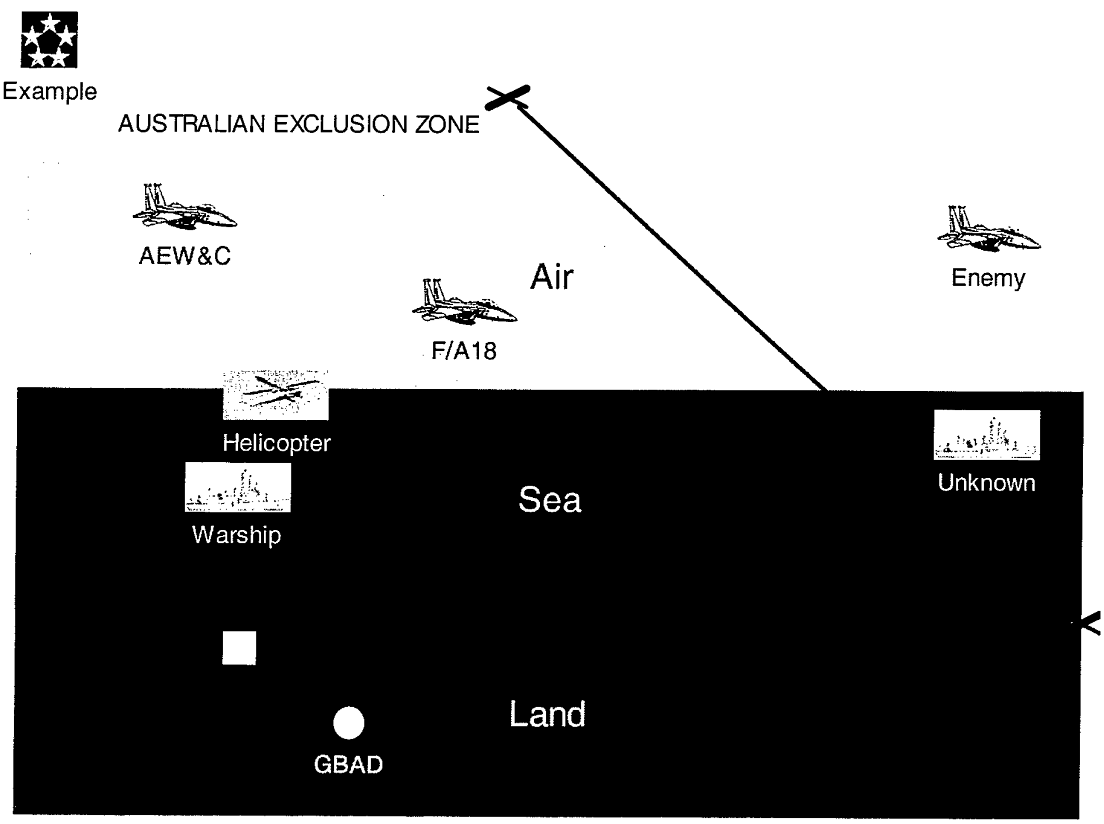

Figure D-1: Operational Concept – Platform Placement

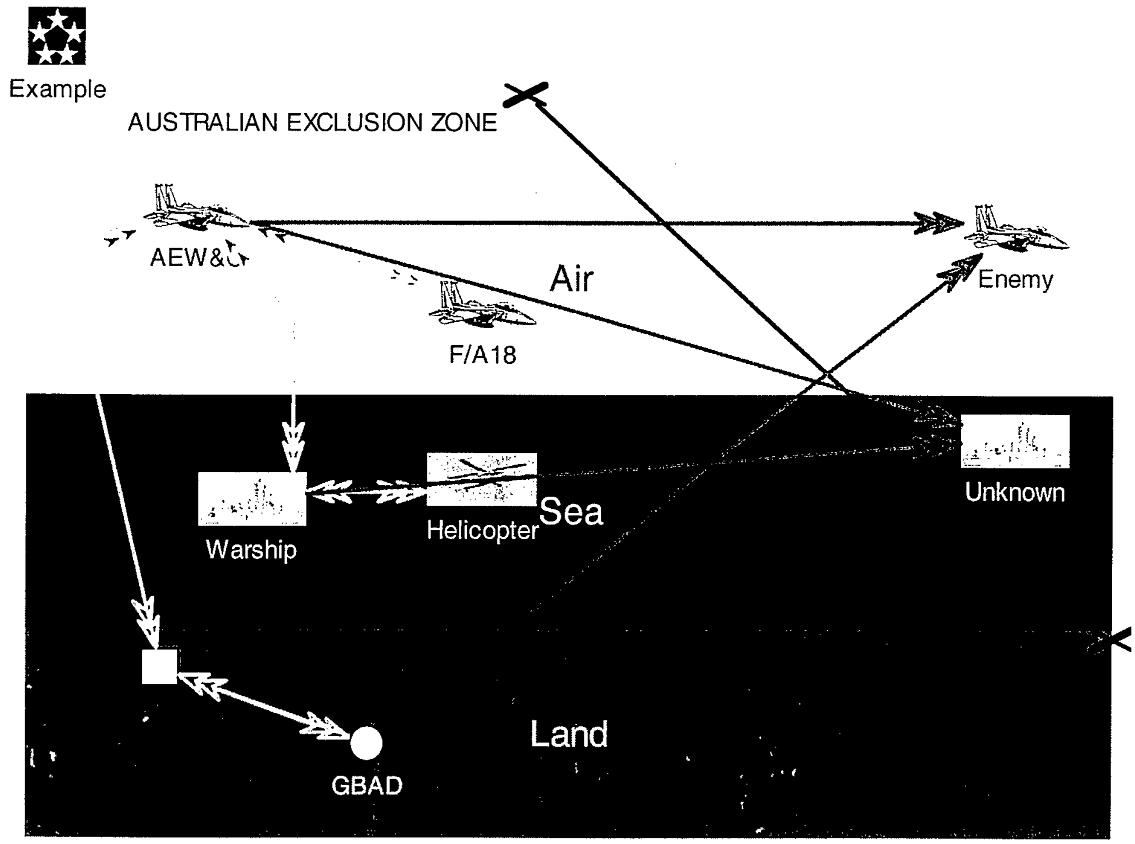

Figure D-2: Operational Concept - Communication (Green) and Surveillance (Red)

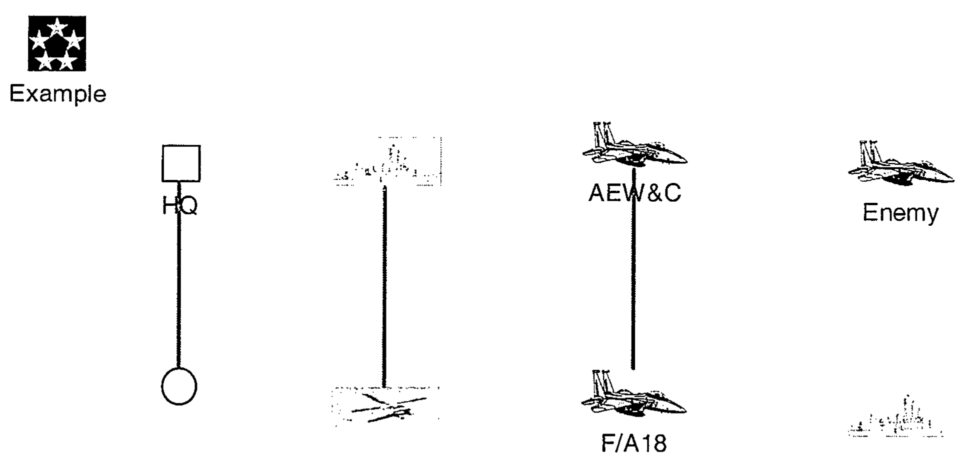

Figure D-3: Command (Red) and Control (Green) Relationships

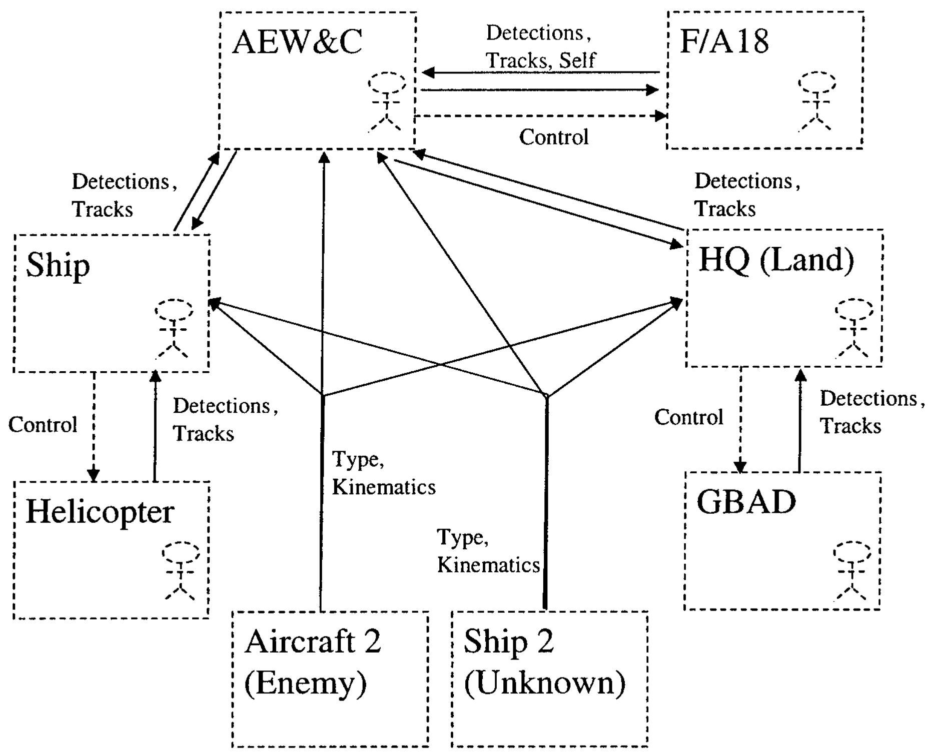

Figure D-4: Information flows.

Appendix E: Maritime Architecture "Use" Case

Description

The DSTO Takari program is concerned with the role that information plays in modern warfare. Information itself has no value if it does not enhance the effectiveness of operations and making such an assessment is at the heart of the tactical testbed concept.

The tactical testbed concept calls for the existence of a human-in-the-loop simulation environment in which missions can be simulated and the impact upon operational effectiveness of enhanced information availability assessed. In particular, connecting the Virtual Ship as a node of EXC3ITE will facilitate access to the services that provide data such as imagery, military geographic information (MGI) and operational pictures. The Virtual Ship will be configured to represent in-service platforms and immersed in a synthetic environment that includes high fidelity representations of the threat environment. As the scenario unfolds, the information available to the ship through its organic sensors will be supplemented by that available from EXC3ITE. As an example, a tactical picture combining data from AEWC and JORN may cue the ship to the existence of an inbound air threat, beyond the horizon.

In addition to supporting an assessment of the impact of information on operational outcomes, this process will support integration of C^4ISR systems with the ship's combat system and the development of tactics and procedures that exploit information availability.

Particular investigations supported by this capability are as follows.

1. *Assessment of the value of information.* Through the conduct of simulated missions both supported by access to enhanced information and not, some assessment of the value of the information in terms of operational outcomes will be made.

2. *Development of procedures and tactics that exploit information.* Access to reliable and timely additional information holds the prospect of not only improving operational effectiveness *per se*, but enabling new ways of conducting missions. The human-in-the-loop simulation environment will permit experimentation concerning new procedures and tactics.

3. *Integration of C3I data within the combat system.* Provision of information in a stand alone capacity is expected to have a positive impact on operational effectiveness. However, it is proposed that effectiveness will be further enhanced if it is integrated with the ship's combat system to allow easy access and manipulation, including fusion with the information provided by the ship's organic sensors. A human-in-the-loop simulation environment will provide a test-bed within which integration requirements can be explored.

Example Scenario

This scenario is named ?.

A number of frigates are escorting a collection of high value units into an archipelagic region. There is a threat of attack by hostile aircraft armed with anti-ship cruise missiles. Based on intelligence, a threat-axis has been assumed and used to position the ships in the task group so that the anti-ship missile defences of the escorts can provide maximum protection of the high value units. However, if an attack comes from a direction that deviates too greatly from the assumed threat axis, the threat to the high value units is significantly increased.

Subsequent events may be explored under two alternative circumstances.

Case 1: The task group must rely on the tactical picture generated by its organic sensors alone. The picture is therefore horizon limited for sea-skimming anti-ship missiles. The in-bound aircraft will most likely need to make limited use of radar in order to target the task group. This offers the prospect that electronic support measures will provide some prior warning of an imminent attack.

Case 2: The area of operations is within the coverage of JORN and conditions permit compilation of a reliable operation picture to a range well beyond the horizon of the task groups organic sensors. Through a satellite link to the EXC3ITE network the task group commander is being fed an almost real-time operational picture (referred to as the C3I picture). This is either presented on a stand-alone display, or is integrated with the ship's combat system to the extent that the organic picture and C3I picture are fused. The commander is alerted to the possible presence of inbound hostile aircraft, well before weapon release range. Despite not being able to confirm the identity of intent of the aircraft at this stage, the commander reorients the task group about a new threat axis, thereby improving the degree of protection provided to the task group.

Outcomes

The outcomes of applying human-in-the-loop simulation in support of this application will be:

1. Assessments of the operational utility of certain types of information.

2. A human-in-the-loop facility for developing procedures and tactics that exploit enhanced information availability.

3. A test bed for developing approaches to integrating new sources of information with the ship's combat system.

4. In conjunction with 3, command support systems may be demonstrated and exercised within realistic scenarios. These systems will support the execution of the new procedures and tactics that exploit enhanced information availability. The output will be recommendations concerning the suitability of command support systems and recommendations for their improvement.

It is noted that the principal outputs will be statements of advice. The strong emphasis upon human-in-the-loop simulation will generally preclude the compilation of traditional measures of effectiveness and performance.

Entities

Within this scenario the entities are described as high-level and low-level. The high-level entities are complex and composed of multiple instances of low-level entities (see 4.2).

The high-level (composite) entities are:

Warships
High value units (e.g. supply/troop ships)
Hostile aircraft
Anti-ship cruise missiles
Anti-missile missiles
C3I network
JORN

The low-level (component) entities are:

Radar
ESM
IRST
C^2 system
Human operator

Note: The C^2 system performs functions of data input, processing and display. If required it could be decomposed into such entities.

Intrinsic Behaviours

The intrinsic behaviours of the low-level entities are shown in Table E-1. The high-level entities derive their intrinsic behaviours from the low level-entities of which they are composed. This in indicated in Table E-2.

Table E-1: The low-level (component) entities, their intrinsic behaviours, data inputs and outputs.

Entity	Behaviour	Inputs	Outputs	Fidelity
Radar	Transmits EM radiation and detects the signal scattered by targets and the environment.	Target identity, position, velocity, orientation (as provided) Environmental parameters (upon change) Control commands (as issued)	Own identity, position, velocity, orientation (as required to maintain accuracy) Tracks (periodic ~1 Hz) System state data	Med
ESM	Detects EM emissions of radars and communicati ons equipment.	Target identity, position, velocity, orientation (as provided) Environmental parameters (upon change) Control commands (as issued)	Own identity, position, velocity, orientation (as required to maintain accuracy) Tracks (periodic ~1 Hz) System state data	Med
IRST	Detects EM emissions of entities in the infrared part of the spectrum.	Target identity, position, velocity, orientation (as provided) Environmental parameters (upon change) Control commands (as issued)	Own identity, position, velocity, orientation (as required to maintain accuracy) Tracks (periodic ~1 Hz) System state data	Med
C^2 system	Receives, processes, displays and outputs data Enables implementati on of human operator intention	Detections, tracks (periodic ~1 Hz) Control commands (as issued by human operator)	Detections, tracks (periodic ~1 Hz) Tactical picture (upon change) Recommendations for action (as required) Control commands (as required, to warship components & subordinate entities)	Med

Human operator	Receives data, views graphical representations of data, assesses the situation, decides on a course of action and implements it	Tactical picture (upon change) Recommendations for action (as required)	Control commands (as required, to C^2)	High

Table E-2: The warships (high-level/composite entities) derive part of their behaviour from their low-level constituent components.

High level entity	Behaviour derived from low level entities
Warship	Transmits EM radiation (Radar)
	Detects scattered EM radiation (Radar)
	Emits EM radiation (IR)
	Detects transmitted EM radiation (ESM)
	Processes data (C2)
	Displays data (C2)
	Launches weapons (C2)
	Moves

Table E-3: The high-level (composite) entities, their intrinsic behaviours, data inputs and outputs.

Entity	Behaviour	Inputs	Outputs	Fidelity
Warship	Moves Scatters EM radiation		Own identity, position, velocity, orientation (as required to maintain accuracy)	Med
High value unit	Moves Scatters EM radiation Responds to movement control commands from warships	Movement control commands (as issued)	Own identity, position, velocity, orientation (as required to maintain accuracy)	Med
Hostile aircraft	Moves Scatters EM radiation Emits EM radiation in IR and as it operates radar Launches anti-ship cruise missiles		Own identity, position, velocity, orientation (as required to maintain accuracy) EM emission description Weapon launch commands (as required)	
Anti-ship cruise missile	Moves Searches for and detects targets Emits EM radiation if RF seeker	Target identity, position, velocity, orientation (as provided) Environmental parameters (upon change) Control commands (including launch commands, as issued)	Own identity, position, velocity, orientation (as required to maintain accuracy) EM emission description	Med

Anti-missile missile	Deploys in response to launch command Moves Receives EM radiation scattered from target (if semi-active seeker)	Target identity, position, velocity, orientation (as provided) Environmental parameters (upon change) Control commands (as issued)	Own identity, position, velocity, orientation (as required to maintain accuracy) EM emission description	Med
C3I network	Provides data, including imagery and operational pictures in the form of tracks	Requests for data (as required)	C3I data (as required)	Med
JORN	Transmits EM radiation and detects the signal scattered by targets and the environment.	Target identity, position, velocity, orientation (as provided) Environmental parameters (upon change) Control commands (as issued by a human operator)	Own identity, position, velocity, orientation (as required to maintain accuracy) Tracks (periodic ~1 Hz) System state data	Med

Static Relationships

The warships are composed of low-level entities, as indicated in Table E-4.

Table E-4: The warships are composed of low-level entities.

High level entity	Is composed of low level entities
Warship	Radar
	ESM
	IRST
	C^2 system

The warships exerts command and control over the missiles that they launch. A single warship exerts command and control over other warships and the high value units.

The hostile aircraft exert command and control over the anti-ship cruise missiles that they launch.

Interactions

The interactions between the entities are shown in Table E-5.

Table E-5: The interactions between high-level (composite) entities.

Initiating entity	Interaction	Receiving entity
Warship	Launches	Anti-missile missile
Warship	Sends message (C^2)	Warship
Warship	Sends message (C^2)	High value unit
Hostile aircraft	Launches	Anti-ship cruise missile
Anti-missile missile	Intercepts	Anti-ship cruise missile

Scenario Execution

Tasks

The warships move.
The high value units move.
The hostile aircraft move.
The warship operates radar, ESM and IRST sensors.

The warship directs the high value units.
The hostile aircraft target the task group.
The hostile aircraft launch anti-ship cruise missiles.
The warship C2 system receives an operational picture via the C3I network.
The task group repositions to reflect the axis of attack.
The C^2 system receives data from radar, ESM and IRST.
The C^2 system presents a tactical picture to the warship commander.
The C^2 system fuses the local tactical picture and C3I picture.
The commander decides a course of action in response to presented data.
The commander implements a course of action through the functionality provided by the C^2 system.
The warship launches anti-missile missiles.
The anti-missile missile destroys the anti-ship cruise missile.
The anti-ship cruise missile destroys a warship or high value unit.

Initial conditions

The task group is at a specified location, travelling on a specified course at a specified speed. The arrangement of ships in the task group is specified.
The hostile aircraft are at a specified location, travelling on a specified course at a specified speed. The intent of the hostile aircraft is to attack the task group.

Termination conditions

The raid by the hostile aircraft is completed. Either the anti-ship cruise missiles have been destroyed, or otherwise rendered harmless, or they successfully detonate in the near vicinity of a warship or high value unit.

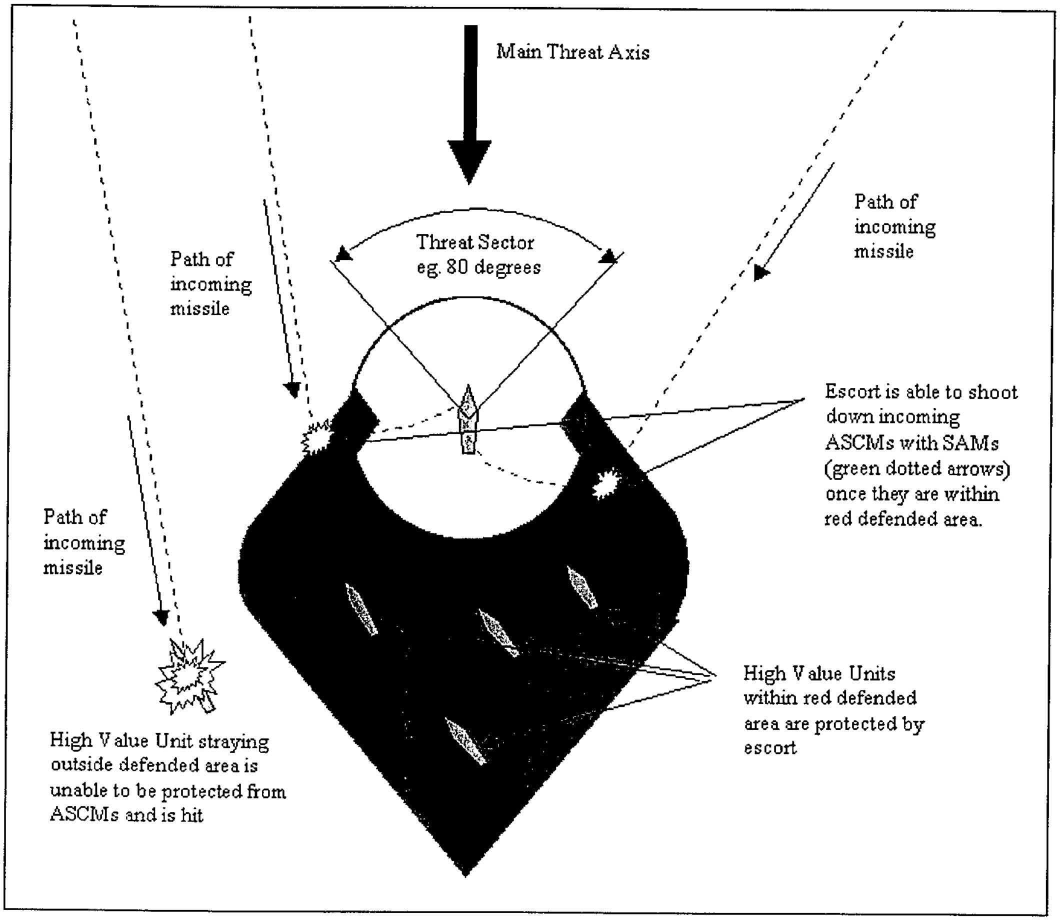

Figure E1: The area that a single warship can defend is a function of the expected threat axis.

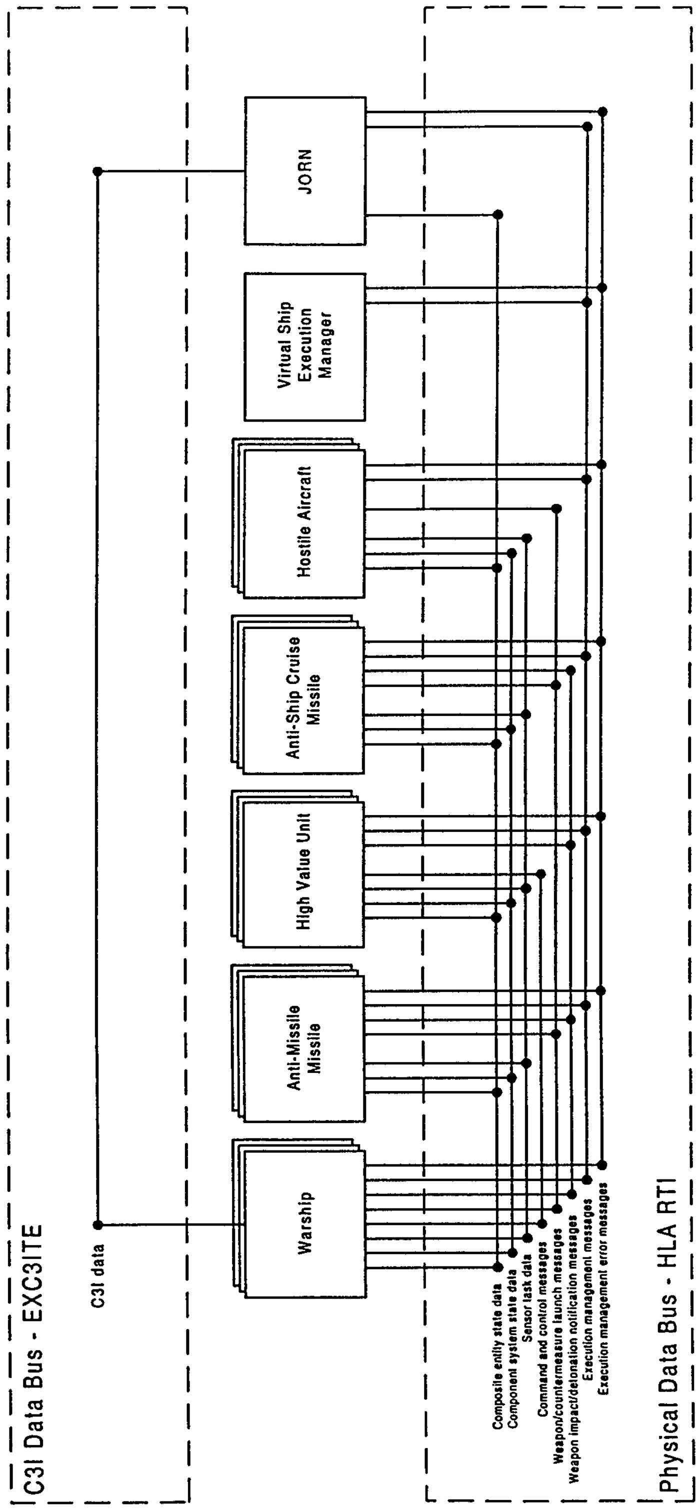

Figure E2: A concept for a federation that supports investigation of the role that information available through the C3I network may play in enhancing operational effectiveness. In this case EXC3ITE provides the C3I data bus and the HLA RTI provides the physical data bus that enables the physical interaction between the entities to be modelled.

Appendix F: Land-Air "Use" Case

Description

This environment is based around the proposed scenario for the forthcoming Virtual Air Environment – LOD experiment which is to explore issues of command and control and coordination between air assets and a land task force. The basic work is to be extended by the Land Air Systems task which is part of LOD's research program. Its aim is to provide advice on systems of systems integration and operations analysis to support the development of doctrine (and TTPs) plus training for an armed reconnaissance helicopter (ARH) capability, and other key Land Air Systems, operating as part of a combined arms team in a Joint operation.

A major component of this task is aimed at understanding and evolving the dynamic teaming of Land Air systems. These systems include: ARHs, Tactical UAVs, GBAD, fixed wing strike, ground based indirect firepower, and a range of ground based units. As a consequence the task seeks to include the study of Joint processes across the Land – Air boundary that enable teaming, synchronisation and coordination of Land Air teams.

As this aim closely matches some of the goals of the Virtual Air Environment (VAE), much of the program of effort outlined below has been designed to meet both the requirements of the Land Air Systems task and the VAE. In addition, the experiments are designed to meet the goals of a number of other LOD tasks (Support to Project Air 87, Land Battlespace Awareness, Land Sensor to Actor Architectures) and have the potential to support some of the aims of tasks in Weapons Systems Division, Joint Systems Branch, and the Theatre Operation Group.

The key to this scenario is that the entity based situation creates a great deal of complexity to task and potentially overload the human players.

Example Scenario

This scenario is named *CAIRS in support of Brigade operations.*

Kamarian forces have achieved a political embarrassment for the Australian government by landing a force (Bde-) within the Australian mainland and occupying the town of Katherine. Australian forces have regained the Tindal air base and are set to mount an offensive to clear Katherine of the remaining Kamarian forces.

The Kamarian air force continues to taunt the RAAF with repeated incursions from the North into Australian airspace. The Australian air defence is being coordinated from NORTHROC who are continually monitoring enemy air tracks being detected by both microwave radar and the JFAS sensor.

A 1TF based combined Arms Team (CAT) attack is ordered to secure Katherine, with a Sqn of ARH tasked to destroy enemy armour (Tanks) north of Katherine which would otherwise become a support force for the main enemy units within the township. The enemy tanks were spotted by SF units in the area.

The assault is to involve a Sqn of ARH tactically flying to the NE of Katherine. Prior to the ARH engaging the enemy, who will be well concealed in a hide, with possible shell scrapes and hard to acquire whilst stationary, the blue commander has called for a CAIRS mission of two F/A-18 to destroy as many enemy tanks as possible. The intention is to drive the remaining tanks from cover and hence make them available for the ARHs to defeat in detail.

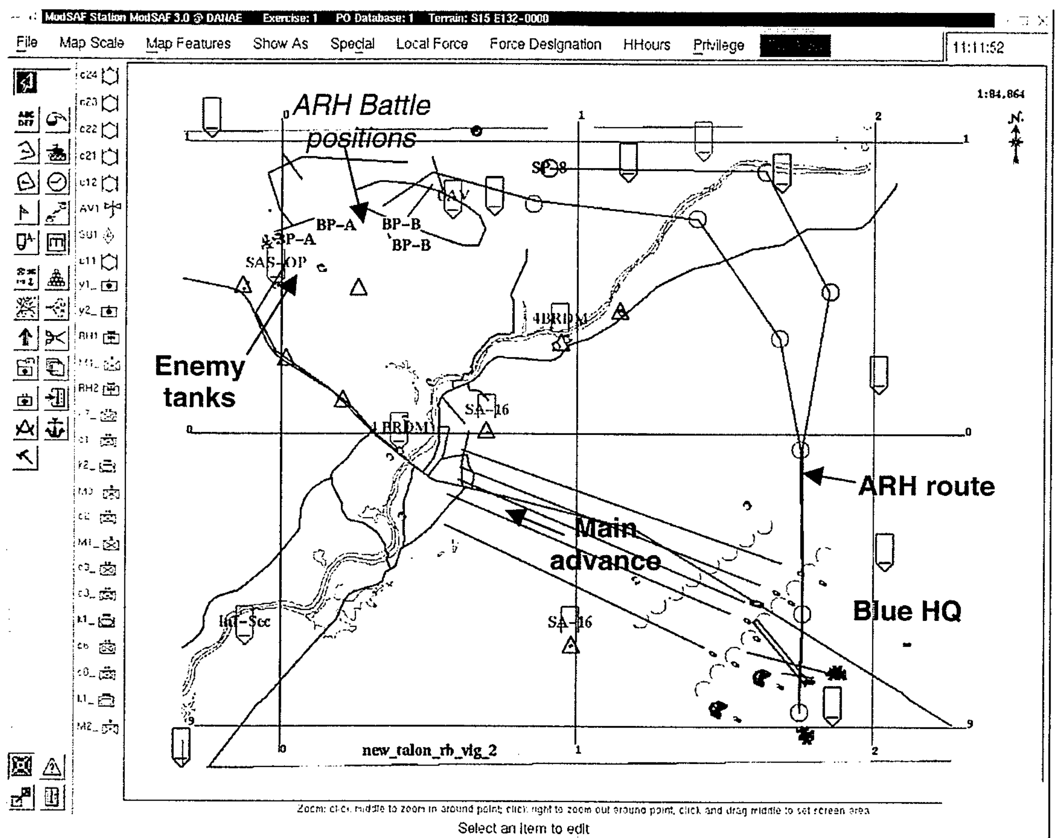

Figure F-1: Example scenario.

An airborne Forward Air Controller (FAC) is to mark the target area using white phosphorous rockets from a specially designated pair of ARH. A RAAF EP-3 will provide electronic suppression to reduce the danger of enemy GBAD acquiring the blue aircraft.

Prior to the arrival of the CAS pair of F/A-18, the JFAS detects a pair of enemy fighters manoeuvring offshore from Darwin. Another pair of F/A-18 is taken off CAP to intercept and ensure safe passage of the CAS aircraft into the JFACA. This part of the scenario is to be provided as the Air use case by AOD.

The CAS pair successfully enter the Joint Force Air Operations Area (JFAOA), under EASTROC control and are handed over to the Tactical Air Operations Centre (TAOC) within the Theatre command. Coordination occurs and the aircraft are directed to the initial CP (contact point, of which a number are pre-defined and must be identifiable by the pilots from the visuals). Other, low air movements must also be taken into account (such as the ARHs and a separate Blackhawk air-mobile operation to provide an infantry coy attack at Manboloo). The pair then hand-off to the JOSCC controller (within the Bde HQ), who further refines the mission and may advise another CP, for example in response to the EP-3 picking up an enemy GBAD site. Finally the FAC takes over control of the aircraft and brings them in, whilst coordinating the target marking using the white phosphorus rockets. The F/A-18 pair split, do their manoeuvre and exit under the control of the FAC, JOSCC and TAOC. Once clear, the ARH move in and defeat any remaining enemy armour.

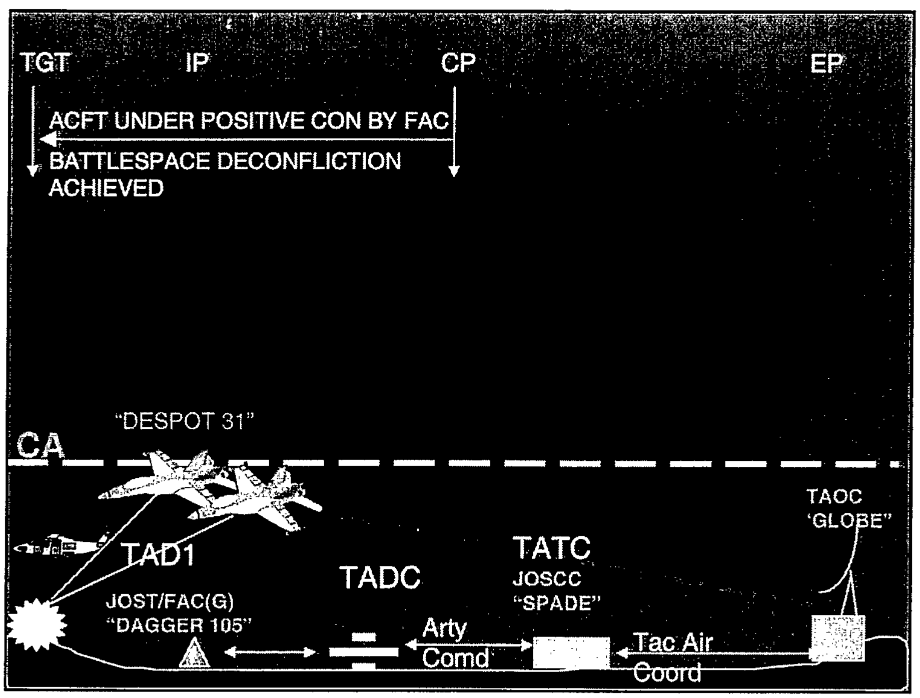

Figure F-2: Scenario.

Outcomes

The outcomes for this scenario are to explore the issues associated with sharing of situational awareness information between the various levels of command and between RAAF and Land systems. The impact of the extra information on the tactics, techniques and procedures will be considered and used to develop new doctrine. An important impact which isn't covered explicitly in this description is all the tasking and prioritisation which must occur prior to the actual mission commencing. LOD is also interested in how this occurs and what tools could be employed to help.

Entities

There are many entities in this scenario – estimated total would be of the order of 2000 entities within the constructive environment, with 2 virtual ARH, 2 virtual F/A-18, 3 levels of HQ and a few virtual sensors (UAV and SF).

Table F-1: Entities

Entities	Side	played	description
ASLAV, APC, light armour, DI	Blue	constructive	Forms the main advance up toward Katherine. Will constitute many hundreds of entities, all with sensor and firepower capabilities.
Artillery units with fire locating radar	Blue	constructive	In support of main advance
Bde HQ	Blue	human	Plays essential roles in the study. Fed with info via BCSS. Special roles are GBAD commander, JOSCC, Artillery coordination, ACE (air control element), TACP.
ARH Sqn	Blue	constructive	Main ARH force is constructive
ARH FAC pair	Blue	virtual	Flown in LOD's virtual sim
FAC	Blue	human	Actual FAC in one of the virtual ARH
UAV	Blue	virtual	Gives virtual UAV pictures back to HQ
EP3-C	Blue	constructive	Provides EW coverage and generates SA
Blackhawks	Blue	constructive	Perform airmobile op to the South
Special force units	Blue	constructive/ human	Played constructively, but human players (EXCON) use virtual imagery to feed intelligence back to HQ
GBAD	Blue	constructive	Under control of human controller in HQ
F/A-18	Blue	constructive	Other F/A-18 in Stage

F/A-18	Blue	virtual	CAIRS pair
SCC	Blue	human	Played from EASTROC
BRDM + T72	Red	constructive	Enemy armour
Other BRDM + DI	Red	constructive	Enemy force in Katherine
SA-7, SA-16 GBAD	Red	constructive	Enemy GBAD sites + sensors
fighters	Red	constructive	Enemy air in Stage
helos	Red	constructive	Enemy support helos

Intrinsic Behaviours

If we focus on the behaviours of those entities associated with the CAIRS mission, the intrinsic behaviours are:

Table F-2: Intrinsic Behaviours

Entity	Behaviour	Inputs (description, rate, fidelity)	Outputs (description, rate, fidelity)	Fidelity
Detection				
GBAD sensors	Detects aircraft	Aircraft entity positions	Detections, tracks	Med
SF units	Detects enemy	Visual (virtual)	Reports	Med
UAV	Detects enemy	Visual (virtual)	Reports	Med
SCC	Gives air picture	Entity positions	RAP, via SA tools	High
JOSCC	Coordinates airspace	Entity positions (SA tools)	Messages, reports and commands	High
EP3-C	Detects EW threats	Entity positions	Reports and SA	Med
FAC	Designates target and controls final engagement	Visual (virtual) and via SA tools	Radio messages to aircrew	High
Response				
F/A-18	CAIRS mission	SA information, orders	Position, status, etc via voice and electronic	High
ARH elements	Defeat enemy tanks	Orders	Position, status, etc	Med
GBAD (red)	Kill blue air	Sensor info	Missile!	Med

Interactions

Table F-3: Interactions

Initiating entity	Interaction	Receiving entity
Bde HQ	Stands down	Blue GBAD
Bde HQ	Primes	Blue GBAD
Bde HQ	Hands over control of F/A-18	FAC
Bde HQ	Directs	F/A-18
EASTROC	Hands over control of F/A-18	Bde HQ
FAC	Directs	F/A-18
FAC	Designates	F/A-18
UAV	Reports	Bde HQ
SF	Reports	Bde HQ

Scenario Execution

Initial conditions

Units are located in their starting positions
F/A-18 are in the air above Darwin
Enemy GBAD is active

Terminating conditions

CAIRS mission is complete and ARH Sqn have defeated enemy armour, or CAIRS aircraft shot down by Red, or enemy armour escapes blue ARH.

Appendix G: Air Architecture "Use" Cases

Air Use Case 1

Description

The purpose of this environment is to support capability development and acquisition in the area of advanced EW systems for rotary wing aircraft. In particular, the environment contributes to the evaluation of the military effectiveness of such systems.

The application provides a capability to conduct human-in-the-loop simulations with high fidelity models of Electronic Warfare Self Protection (EWSP) equipment. An important component of such EW systems is the operator interface and this has a major influence on the application of successful countermeasures such as aircraft manoeuvres. Through the inclusion of the operator in the simulation, the environment will provide a capability to investigate operator decisions in respect of the correct manoeuvre response required for a given situation.

Example Scenario

The scenario is named Black Hawk Airmobile Mission.

An Australian Task Force has been deployed to support a coalition contingent.

An Aviation Regiment (Avn Regt) has been deployed to the Area of Operations (AO) to provide airmobile support to an Australian Infantry Brigade. The Commander Australian Theatre has tasked the Brigade Commander to establish and secure a Point of Entry (POE) airfield to be used as the Brigade Maintenance Area (BMA).

Reconnaissance elements of a Battalion of the Royal Australian Regiment (RAR) has completed a successful sweep in the vicinity of the POE Airfield, and has radioed back to Battalion HQ that the area is free from enemy patrols. The Commander of the Aviation Regiment has been tasked to conduct an airmobile to insert a company minus force, to secure the airfield until the remainder of the Battalion of the RAR can be deployed by C-130 tactical transport. The Commander the Avn Regt has tasked a Black Hawk Squadron, with direct support from gunships, to plan and conduct the activity.

The Air Mission Commander has received an intelligence briefing on the enemy's disposition and likely intentions. To date the enemy's activities have been small-scale (up to platoon size) conducting harassment/diversion operations in an attempt to force the coalition force to deploy its assets away from enemy concentrations.

The enemy has anticipated a considerable air threat, and this is reflected in their Electronic Order of Battle (EOB). The greatest threats to coalition aircraft within the AO are the radar guided SAM's and radar guided AAA. Locations of possible enemy anti-aircraft threats have been marked on a map for mission planning purposes.

The airmobile mission will be conducted with four S-70A-9 Black Hawks to provide the company minus lift, and a light fire team of two gunships to provide armed escort. The formation will transit in tactical formation spacing , via the planned route. The formation of Black Hawks, accompanied by the light fire team, will depart the squadron location to the Pick Up Zone (PZ) to load the company minus from the Infantry Battalion. After the notional loading time, the Black Hawks will depart the PZ and transit to the Landing Zone (LZ), in company with the light fire team via the route marked to arrive thirty seconds after the gunships.

The gunships will provide cover for the Black Hawks on the ground in the PZ, by flying a figure of eight pattern around the LZ. After the notional time for deplaning, the Black Hawks will depart the PZ and return to the squadron's home location via the reciprocal route.

The Air Mission Commander has briefed all the mission aircrew to conduct SOP actions on contact with known or 'pop up' RF threats. This will include the prosecution of threats by gunship direct fire support.

Outcomes

The outcomes from this simulation trial were to demonstrate the relative impact of different EW systems and their interfaces on mission effectiveness.

Entities

The entities within this scenario can be classified as *Virtual Simulation* or *Constructive Simulation* entities.

Table G-1 Entities

Entity	Side	Played	Description
Black Hawk HiL	Blue	Virtual	Flown in AOD virtual flight simulator
Black Hawk (3 of)	Blue	Constructive	Fly formation around Black Hawk HiL
Gunships (2 of)	Blue	Constructive	Fly formation around Black Hawk HiL
SAM – radar guided	Red	Constructive	Enemy SAM sites
AAA - radar guided	Red	Constructive	Enemy AAA sites

Intrinsic behaviours

Table G-2: Intrinsic behaviours

Entity	Behaviour	Inputs	Outputs	Fidelity
VIRTUAL				
Black Hawk	Fly air mobile mission	EW information	Position, status	High
CONSTRUCTIVE				
Black Hawks	Maintain formation about HiL Black Hawk	HiL Black Hawk position	Location	Med
Gunships	Maintain formation about HiL Black Hawk	HiL Black Hawk position	Location	Med
SAMs	Kill blue air	Sensor info	Missile	Med
AAAs	Kill blue air	Sensor info	Bullets	Med

Interactions

The interactions among the entities are:

Table G-3: Interactions among the entities

Initiating Entity	Interaction	Receiving Entity
HiL Black Hawk	Dictates other blue forces location	Other blue force air platfroms

Scenario Execution

Tasks

Black Hawk formation is required to navigate between Pick Up Zone and Landing Zone.
Avoid threats where possible.
Survive encounters with Pop-up threats.
Arrive at Landing Zone with formation intact.

Initial Conditions

Black Hawk formation and escort are on the ground at the Pick Up Zone.

Termination Conditions

Black Hawk formation and escort arrive at the Landing Zone or HiL Black Hawk is destroyed by enemy fire.

Air Use Case 2

Description

The Virtual Air Environment (VAE) is an Australian Defence Department initiative that aims to provide embedded training capabilities for the Australian Air Defence System. The concept combines live, virtual and constructive simulations, using distributed simulation to selectively stimulate core operational systems. This is a joint activity between the Royal Australian Air Force (RAAF) and the Defence Science and Technology Organisation (DSTO) to determine what is possible with current and emerging technologies.

The initial phase of the VAE focuses on Air Defence Controller training. The vision is to extend it to the entire Air Defence System (with similar developments in the maritime and land environments). To determine the structure of a mature VAE, an iterative approach of feasibility demonstration and requirements definition is being used. To this end concept demonstrations are being conducted.

A series of scenarios has been developed which use both constructive and virtual simulation to stimulate the command and control aspects of the operational Air Defence System. The scenarios are distributed with players in different localities. The constructive and virtual simulations are located at DSTO Melbourne, and the operational Air Defence Controllers (ADCONs) are located at RAAF Base Williamtown, N.S.W

Example Scenario

The scenario is named VAE_DEMO_1.

This scenario is aimed at providing different entities on the ADCONs display and is not a specific tactical scenario. It involves four virtual entities (at DSTO Melbourne) and one ADCON (at RAAF Base Williamtown). The virtual entities comprise:

- 1 computer generated entity from STAGE – a C-130 Hercules,
- 2 computer generated entities from BattleModel – a pair of F/A-18 Hornets, and
- 1 HiL – a pilot flying an F/A-18 simulator in the AOSC partial dome.

The scenario evolves as shown in Table G-4.

Table G-4: Description of scenario

Serial	Time	Activity
1.	0 mins	The C-130 is flying a route from Darwin to Tindal.
2.	5 mins	The F/A-18 pilot in the simulator scrambles from Tindal.
3.	8 mins	The F/A-18 pilot is instructed by the ADCON to intercept the C-130.
4.	20 mins	Two BattleModel F/A-18 aircraft take off from Tindal.
5.	24 mins	The F/A-18 pilot is told by the ADCON to intercept the two F/A-18s.
6.	35 mins	The pilot intercepts the F/A-18s

The pilot visually identifies the C-130 and F/A-18 aircraft at each intercept and the scenario concludes with the identification of the two BattleModel generated F/A-18s. The scenario can be expanded to include 50 virtual entities (25 each from BattleModel and STAGE) with up to 8 (consisting of pairs of F/A-18s each from BattleModel and STAGE) able to be controlled by an ADCON. Other aircraft involve a mixture of civilian and military, light and commercial categories. The entities are located in the Darwin-Tindal area

Outcomes

The outcome of this exercise is to demonstrate that an ADCON has the appropriate Situation Awareness Display to be able to control the simulated (as well as real world) entities. This exercises the command and control system.

Entities

The entities within this scenario can be classified as *Live*, *Virtual* or *Constructive Simulation* entities.

The Live Simulation entities are:

- Air Defence Controllers (ADCONs) and selected parts of the Air Defence System

The Virtual Simulation entities are:

- F/A-18 HiL simulator with high field-of-view visuals

The Constructive Simulation entities are:

- C-130 (generated by STAGE)
- F/A-18 (generated by BattleModel and STAGE)

- Commercial aircraft
- Light aircraft

Scenario Execution

Table G-5: Summary of activities which can be undertaken with respect to VAE_DEMO_1.

Activity	Description
Rehearsal	All entities start at t=0 minutes and continue until the end of scenario (t=35 minutes).
Demonstration	HiL and STAGE start at t=0 minutes. BattleModel CGFs start at t=20 minutes. STAGE CGF stopped at t=20 minutes.
Test 1	This includes up to 30 entities and comprises: one HiL, nine STAGE generated C-130s, and 20 BattleModel generated F/A-18s. Partway through this test, one circling F/A-18 will be generated using VR-Link from Williamtown.
Test 2	This includes up to 50 entities, and comprises: no HiL, 29 STAGE generated C-130s, 20 BattleModel generated F/A-18s and one circling F/A-18 generated using VR-Link from Williamtown.

Experimental Description

The main demonstration takes place at 3CRU where the Phoenix display is located, and consists of:

- an Air Defence Controller at the Phoenix Display (which shows actual air traffic as well as the four virtual entities), communicating with the pilot in the F/A-18 flight simulator to facilitate his intercepts with the artificial entities,
- a PC running Microsoft NetMeeting software which allows the visual scene in the AOSC partial dome display to be viewed. Later this PC is used to generate a virtual entity (a circling F/A-18) which is displayed on all systems (Test 1 and Test 2),
- a situation awareness display which shows a plan view of the location of all virtual entities,
- Stealth, a DIS utility that shows the outside view as would be seen by a simulated entity.

The DIS-DTE gateway software is located on a PC at 3CRU.

At AOD, DSTO, Fishermans Bend, the set up in the AOSC comprises:

- a video screen of the pilot in the F/A-18 cockpit in the partial dome display,

- the STAGE screen, showing the location of all virtual entities,
- the BattleModel screen and BattleView, showing the location of all virtual entities,
- a situation awareness display (same as at 3CRU),
- a Phoenix screen, showing all four virtual entities (but no actual air traffic),
- an intercom allowing voice communications between the ADCON and the pilot to be heard,
- a projector showing the image of the pilot in the partial dome, and
- a displayed outline of the scenario and its evolution.

The pilot in the F/A-18 simulator with partial dome display is located in the next room. The pilot communicates with the Air Defence Controller via a standard phone line. The DIS logger and the UNIX utility "tcpdump" are used to capture DIS and network data traffic for later analysis.

Appearance Of Entities

Four virtual entities will appear correctly (geographic position, speed, altitude, etc.) on the 3CRU Phoenix display system in Williamtown alongside normal air traffic movements.

There were several other displays which show the evolution of the scenario. A Phoenix display screen, also set up in the AOSC control centre, shows only the simulated virtual entities participating in the scenario, whereas the real system will also show normal air traffic movements.

STAGE will receive all DIS PDUs, and consequently display the F/A-18 pilot in the partial dome simulator, the two BattleModel generated F/A-18s, and its own C-130, on its situation awareness display.

The BattleModel viewer, BattleView, is also able to display all incoming PDUs and shows the position of the pilot in the F/A-18 simulator, the C-130 generated by STAGE as well as the two F/A-18s generated by BattleModel.

The AOSC control centre has a situation awareness display which will also show all four virtual entities. This situation awareness display is also available at RAAF Williamtown.

The pilot visually identifies the C-130 and F/A-18 aircraft at each intercept, and the scenario concludes with the identification of the two BattleModel generated F/A-18s. The scenario lasts a total of 35 minutes.

Measures

Table G-5 presents various measures as each stage of the scenario is executed. The various stages in the scenario are identified together with their function and subjective and objective measures. The last column provides a summary of the outcome.

For the scenario to evolve as expected, the gateway must pass the virtual entities to the tracking computer (MV 15000), which then converts them for display on the Phoenix system. All sites should observe the virtual entities at the appropriate times with the appropriate characteristics.

The purpose of the first serial is to verify data connectivity, correct radar operation, and receipt of a DIS entity at the gateway with subsequent conversion to DTE format. The gateway should show the presence of a single DIS entity (the STAGE generated C-130) and indicate that the entity is in range. Plots for the entity are displayed on Phoenix and a track should be formed by the tracking computer.

The second stage involves adding another virtual entity (the pilot in the F/A-18 simulator) and confirming that the new entity is received at both the 3CRU and DSTO sites. A comparison of position information at both sites should show the information to be the same.

The third stage involves the pilot being directed by the ADCON to intercept the C-130. The ADCON directs the intercept so that the F/A-18 radar detects the C-130 as expected. The ADCON controllers' calls giving azimuth and range should comply with readouts from the gateway.

The fourth stage involves the injection of two more virtual entities (the two BattleModel F/A-18s). These will be observed on the gateway and all displays (Phoenix, STAGE, BattleModel, and the two situation awareness displays at 3CRU and the AOSC) and should show the four entities (one C-130, one HiL F/A-18, two x BattleModel F/A-18s).

In stage five, the HiL pilot in the F/A-18 simulator is directed to intercept the two BattleModel generated F/A-18s.

The sixth stage is the conclusion of the scenario. The outcome should be a successful intercept. This scenario demonstrates that multi-player, multi-radar, dissimilar levels of simulation are possible.

Table G-6: Description, measures and outcomes of each serial of the scenario.

Scenario							
Serial #	**Description**	**Entities**	**Time**	**Objectives**	**Subjective Measures**	**Objective Measures**	**Outcome**
1	Medium speed aircraft at medium altitude flying straight line course between Darwin and Tindal, Squawking M1=11, M2=1234, M3=5555, MC=ON.	CGF1 DSTO (STAGE generated C-130)	0 mins	Verify data connectivity		Gateway will show count of detected DIS entities	Gateway shows the presence of a single DIS entity (STAGE generated C-130)
				Verify radar operation		Gateway will show when DIS entity is in range of radar Phoenix display will show north mark from the simulated radar	The gateway indicates the entity is in range; plots for the entity displayed on Phoenix; and a track formed by the MV tracking computer Phoenix display shows north mark from the simulated radar
				Verify SCION gateway receipt of DIS entity and conversion to DTE		Gateway will indicate when plots are generated. The Summit box's Transmit lights will flash when data is being transmitted to the MV Phoenix display will show plots representing simulated entity	Gateway indicates when plots are generated. The Summit box's Transmit lights flash when data is transmitted to the MV Phoenix display plots representing simulated entity successfully shown
2	F/a-18 depart Tindal, climb to 25,000, heading 340	DSTO Dome (pilot in F/A-18 simulator)	5 mins	Confirm entry of DIS entity at each participating node		Gateway shows an extra DIS entity. It can also show positional information, and range/bearing from radar STAGE allows point & click extraction of positional information of DIS entities	
				Compare position information	Comparisons of readouts over phone		Interpretations of displays at 3CRU and AOD give the same results

3	F/A-18 under CGI direction vector to intercept serial 1 entity	DSTO Dome / 3CRU	8 mins	Verify accuracy of Dome acquisition on radar	Comparison of F/A-18 radar and GCI radar readouts over phone		The GCI should successfully direct the intercept so the F/A-18 radar detects the entity as expected
				Verify GCI Bullseye accuracy on target entity position	Comparison of gateway's indicated azimuth/range with that read by the GCI		GCI Bullseye calls should comply with read-outs from the gateway
4	F/A-18 x 2 depart Tindal, climb to 20,000, heading 040	CGF2 DSTO (BattleModel generated F/A-18s)	20 mins	Alternate CGF generator add entities and verify receipt by all nodes		Gateway shows new number of entities STAGE shows new entities on map	All nodes should show 4 entities (1 C-130, 1 dome F/A-18, 2 x BattleModel F/A-18s)
5	F/A-18 Dome conduct 1 v 2 intercepts against serial 4 entities under CGI control	Dome, CGF1, CGF2, 3CRU	24 mins	The pilot visually identifies the C-130 and F/A-18 aircraft at each intercept, and identifies the two BattleModel generated F/A-18s.	Observe scenario		***HIL pilot in the F/A-18 simulator is directed to intercept the two BattleModel generated F/A-18s. A successful intercept should be achieved***
6	End scenario	All	35 mins	Prove multi-player, multi-radar, dissimilar levels of simulation			

Appendix H: Distributed Simulation Standards

Background on DIS

Distributed Interactive Simulation is a simulation interoperation standard developed from the earlier SIMNET work carried out in the US.

DIS is a broadcast protocol, where information is sent via UDP to all nodes typically within a given subnet. The DIS standard defines a number of categories of messages, called Protocol Data units (PDU), including:

- Entity state PDU (ESPDU), containing the location, directional vectors and appearance codes for an individual entity.
- Fire PDU, sent whenever a weapon fires. This is used to generate the visual appearance of a flash on visual 'stealth' viewers.
- Detonation PDU, generated whenever the previously fired projectile (which may be modelled using entity state PDU's or not, depending on whether it was a missile or a bullet, shell, etc) has been modelled to have reached its detonation point. In response to the detonation PDU, the target must calculate its damage and update this to the rest of the network in its next entity state PDU.

There are other specialised PDU types, including signal PDUs, used to model electromagnetic emissions and to send messages, communication (voice) PDUs for sending digitised voice and others relating to special domains, such as underwater propagation modelling, etc. However for the majority of entity based, real-time simulations, the bulk of the DIS traffic is composed of the three main PDUs detailed above.

The other key ingredient in the DIS standard is the definition of a number of dead-reckoning algorithms used to reduce the frequency of ESPDUs being broadcast. Any simulation entity must broadcast an ESPDU at least once every 5 seconds, or it is assumed to have dropped off the network. However they must also broadcast an ESPDU when they have diverged from their current dead-reckoned position by more than a certain error factor. In this way, other simulators can keep track of the entity at whatever time-step it requires for its internal modelling by dead reckoning from the last known (ESPDU) position. This approach allows, for example, visual stealth viewers that typically refresh the display at 30-60Hz to smoothly extrapolate the position of the drawn models between frames despite the fact that the ESPDUs may arrive at far less frequent intervals.

The DIS standard also defines a complete range of enumeration values corresponding to various country, platform and weapon types.

Background on HLA

High Level Architecture (HLA) is a methodology designed to support distributed simulation exercises. It has been mandated by the US DoD as the replacement for both DIS and ALSP (Aggregate Level Simulation Protocol), a networking protocol used for connecting wargames. HLA development is sponsored by the US Defense Modeling and Simulation Office (DMSO).

HLA has been under development since 1995. On September 21 2000, the Standards Board of the Institute of Electronic and Electrical Engineers (IEEE) voted to accept the HLA as an international standard. When the IEEE standardisation process is completed, there will be three new standards: (1) 1516 - Framework and rules; (2) 1516.1 – Federate interface specification; and (3) 1516.2 - Object Model Template.

The HLA is not a protocol based standard like DIS, but is a set of high-level rules to which a set of interconnecting simulations and simulators (known as a federation of federates in HLA parlance) must adhere. In essence the rules specify that:

- Each of the federates must all define (and document) a Simulation Object Model (SOM) specifying what they are able to share and receive from the rest of the federation.
- The federation must have a documented Federation Object Model (FOM), basically a composite of all the individual FOMs.
- Each federate must communicate through a middleware component known as the run-time infrastructure (RTI). The definition of the RTI calls is part of the HLA specification, however the implementation of the RTI isn't and there exists an number of alternative, incompatible RTIs.

The key to understanding HLA is that the simulations to be connected (federates) must all be capable of understanding elements of each others SOMs. Each SOM is an object-oriented like definition of what objects the federate represents, what the values related to that federate are able to be published for use by others, or subscribed to if it is being picked up from another federate and what classes of interactions the federate will support. Thus each FOM must be compatible with other federates FOMs. This relates not only to the naming of objects (simulation A must use the same name for an entity as simulation B), but also to the rules of how to represent data, how to implement dead reckoning, who determines damage and what constitutes a given interaction. Unlike DIS, HLA does not define any of these conventions and it is left to the federation designers to resolve these issues.

The strict requirement to predefine all objects and interactions and to subscribe and publish to these permits the RTI to be far more efficient in its delivery of data than the crude broadcast seen in DIS. The RTI is able to determine which federate needs to be sent which piece of information and hence significantly reduce the overall network load. Additional filtering based on data ranges, such as location further allows the RTI to avoid delivering data to a federate which is unconcerned with it. As a result, HLA will in theory allow far more scalable networks of federations to be developed than was possible in the network bounded DIS model.

Another benefit of HLA as compared to DIS is the support for time constrained federations to allow simulations operating in different time steps to still interoperate efficiently. This would be particularly applicable to closed, analytical simulations or to physics based engineering models which may not operate in wall-clock based 'real-time'.

Appendix I: Virtual Ship Architecture Working Group (VSAWG) Terms of Reference 21 May 1999

The role of the Virtual Ship Architecture Working Group (VSAWG) is to determine, document and evolve the architecture of the Virtual Ship. Having established a baseline version, the VSAWG will evolve the Virtual Ship architecture in order to maximise the utility of the Virtual Ship. The Virtual Ship architecture will be subject to configuration control.

The VSAWG will operate in a consultative manner and ensure that the technical content of the architecture is guided by the requirements of the user community. Ultimate responsibility for the content of the architecture will reside with the VSAWG.

The architecture of the Virtual Ship will be based upon the High Level Architecture (HLA)†. Models of system components will be the federates of a HLA federation. The federation will be described by the Virtual Ship FOM (VS-FOM), and the development of this will be the principal task of the VSAWG.

Elements of the Virtual Ship Architecture (VSA)

The Virtual Ship will be constructed in accordance with the High Level Architecture. In addition, the specific objective of simulating warship operations necessitates addition to, or specialisation of, the HLA. This collection of additions and specialisations will constitute the Virtual Ship Architecture (VSA).

There will be five essential elements of the VSA. These are described as follows.

The VS-FOM

This defines the data exchange contract amongst the federates that constitute the Virtual Ship. It will be constructed in accordance with the Object Model Template (OMT).

The Virtual Ship Lexicon

The objects, attributes, interactions and parameters within the VS-FOM will form the Virtual Ship lexicon. The lexicon will provide for common terminology use across

† The High Level Architecture is a framework for performing distributed simulation. A number of simulation models, known as federates, operate together to create a common simulated environment. The collection of all federates is known as the federation. In order to operate together the federates must exchange information. The data exchanged amongst federates is described by the Federation Object Model (FOM). The structure of the FOM is determined by the federation developer and federates must be engineered to exchange data in accordance with it. The format of the FOM is given by the Object Model Template (OMT). This is a tabular format that details the objects within the federation, the attributes that describe them, and the interactions amongst the objects which are described by parameters.

modelling applications. It is through the common interpretation of data that a common world view can be established amongst distributed federates.

The Virtual Ship Rules

The Virtual Ship rules will describe mandatory characteristics of federates brought into the Virtual Ship, over and above the HLA rules.

Virtual Ship Data Standards

Different modelling applications relevant to the Virtual Ship have shared interest in data. The provision and exploitation of this data will be facilitated through establishment of common data standards.

The Virtual Ship Tools

A variety of existing tools will support development of the Virtual Ship. In addition to tools that support the HLA generally, a requirement for additional tools can be foreseen. These will support scenario generation and control, federate development, object model consistency checking, federate monitoring including stealth viewing and federation execution management and analysis.

Outputs

The VSAWG will produce the following:

1. A VS-FOM documented in accordance with the HLA OMT,
2. A report describing the principal elements of the VSA, with particular reference to the VS-FOM,
3. A document describing the manner in which the VS-FOM will evolve, including configuration control,
4. A series of working papers documenting the technical considerations on topics of relevance to whole ship simulation,
5. A technical brief on the VSA, which is public release,
6. A non-technical brief on the VSA, which is public release.

Key tasks

The essential element of the VSA is the VS-FOM. Construction of this will drive activity related to the other four aspects of the VSA. The task in constructing the VS-FOM is to determine the objects that will be represented in the Virtual Ship from a data exchange point of view, and the interactions amongst the federates. In the lexicon of the HLA the objects are described by their attributes and interactions are described by their parameters.

The tasks that must be performed by the VSAWG in order to capture these data are to:

1. Identify the ship components that will be modelled and the interactions amongst them,
2. Identify the requirement for data exchange with the outside world, or the scenario,
3. Determine a set of objects and interactions that capture this requirement,
4. Determine the attributes and parameters of the objects and interactions,
5. Determine a lexicon of objects, interactions, attributes and parameters,
6. Determine mandatory requirements (rules) for federates to participate in the Virtual Ship federation executions,
7. Define key enumerated data types and complex data types,
8. Construct the VS-FOM, exploiting object and interaction class hierarchies,
9. Assess the VS-FOM for robustness with respect to the introduction of new attributes, higher fidelity models, lower fidelity models, new object classes and new interaction classes,
10. Identify common data requirements across simulation applications,
11. Identify/specify software tools that will assist in the development of simulation models that are compliant with the VS-FOM.

Process

The VSAWG will meet on a regular basis, at an interval to be determined by the members. Additional meetings may be called as required. Meetings of the full VSAWG are intended primarily as a mechanism for providing rigorous consideration of architecture proposals and decision making concerning these.

The bulk of the technical work involved in formulating the Virtual Ship Architecture will occur out of session. A number of subcommittees will be formed in order to address the data exchange requirement amongst models of various ship systems. For example, a subcommittee may be formed to consider radar modelling and another to consider above water weapons. There will be cross membership of subcommittees to exploit system commonalities. For example, passive sonar and ESM share many similarities and their joint consideration offers the prospect of accelerated progress.

The outcome of subcommittee deliberations will be a series of working papers. These might be profitably published as DSTO Technical Notes, with due recognition of Industry contributions.

These findings shall be brought together by the VSAWG in order to determine the Virtual Ship Architecture. The full VSAWG will subject the architecture proposals of the subcommittees to rigorous analysis, particularly with respect to the issue of robustness as noted above.

Appendix J: Glossary of Acronyms and Terms

AAA	Anti Air Artillery
ADCON	Air Defence Controller
ADF	Australian Defence Force
ADO	Australian Defence Organisation
ADS	Advanced Distributed Simulation
ADSO	Australian Defence Simulation Office
AEW&C	Airborne early Warning and Control
AIO	Australian Imagery Organisation
AO	Area of Operations
AOD	Air Operations Division
AOIM	Area of Interest Manager
AOSC	Air Operations Simulation Centre
ASCM	Anti Ship Cruise Missile
ATM	Asynchronous Transfer Mode
BMA	Brigade Maintenance Area
C2	Command and Control
C^3I	Command, Control, Communications, and Intelligence
C4ISR	Command, Control, Communications, Computers, Information, Search & Reconnaissance ???
CATDC	Combined Arms Training and Development Centre
CD	Communications Division
CGF	Computer Generated Forces
CORBA	Common Object Request Broker Architecture
COTS	Commercial Off The Shelf
DCOM	Distributed Component Object Model
DDG	Guided Missile Destroyer
DERA	Defence Evaluation Research Agency
DICE	Distributed Interactive C3I Environment
DIE	Defence Information Environment
DIS	Distributed Interactive Simulation
DMSO	Defense Modeling and Simulation Office (US)
DoD	US Department of Defense
DSAF	Defence Simulation Advisory Forum
DSTO	Defence Science & Technology Organisation
EMPDU	Emission PDU
EOB	Electronic Order of Battle
ESPDU	Entity State PDU
EW	Electronic Warfare
EWD	Electronic Warfare Division
EWPA	Electronic Warfare Program Arrangement
EWSP	Electronic Warfare Self Protection
EXC3ITE	Experimental C3I Technology Environment
FFG	Guided Missile Frigate

FOM	Federation Object Model
GBAD	Ground Based Air Defence
GOTS	Government Off The Shelf
HiL	Human-in-the-Loop
HLA	High Level Architecture
HQ	Headquarters
HQADF	Headquarters, Australian Defence Force
HQAST	HQ Australian Theatre
IEEE	Institute of Electrical and Electronic Engineers
IMAD	Imagery Management and Dissemination
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ITD	Information Technology Division
J2EE™	Java 2 platform Enterprise Edition
JOD	Joint Operations Division
JORN	Jindalee Operational Radar Network
JSB	Joint Systems Branch
JSE	Joint Synthetic Environment
LAN	Local Area Network
LOD	Land Operations Division
LZ	Landing Zone
MANIFOLD	MANagement of Information by the Federation OF Logical Data
M&S	Modelling and Simulation
MGI	Military Geographic Information
MOD	Maritime Operations Division
ModSAF	Modular Semi Automated Forces
MSEB	Military Systems Experimentation Branch
MWTC	Maritime Warfare Training Centre
OPFOR	Opposition Forces
PA10	Project Arrangement 10
PDU	Protocol Data Unit
POE	Point of Entry
PZ	Pickup Zone
QoS	Quality of Service
RACE	Rapid Application Construction Environment
RAAF	Royal Australian Air Force
RAN	Royal Australian Navy
RAR	Royal Australian Regiment
RF	Radio Frequency
RID	RTI Interface Definition
RMI	Remote Method Invocation
RPR-FOM	Real time Platform Reference FOM
RTI	Run Time Infrastructure
RTM	Requirements Traceability Matrix

SAM	Surface Air Missile
SEDRIS	Synthetic Environment Data Representation and Interchange Specification
SERF	Synthetic Environment Research Facility
SIMNET	Simulator Networking
SOM	Simulation Object Model
SOP	Standard Operating Procedures
SSD	Surveillance Systems Division
STAGE	Scenario Tactical And Generation Environment
TBS	Theatre Broadcast System
TCP	Transmission Control Protocol
TOB	Theatre Operations Branch
TTCP	The Technical Cooperation Program
UDP	User Datagram Protocol
USN	United States Navy
VAE	Virtual Air Environment
WAN	Wide Area Network

Glossary of Terms

The definitions herein are not intended to be rigorous; important features of one M&S category frequently overlap those of another since the degree of human participation and the degree of equipment realism are infinitely variable. With this caveat, the following are generally accepted terms and definitions for the more important models and simulations relevant to Defence.

Model. A physical, mathematical or otherwise logical representation of a system, entity, phenomenon or process.

Simulation. The operation or exercise of a model over time.

Modelling and Simulation (M&S). The term refers to the use of models, including emulators, prototypes, simulations, simulators, stimulators, either statically or over time, to develop data as a basis for making managerial or technical decisions. The terms "modelling" and "simulation" are often used interchangeably.

Analytical domain:

- The majority of simulation models are employed in imitating the behaviour of physical systems (such as aircraft or missiles) which do not require or involve interactive human input. Simulations which require the aggregation of many systems involving human behaviour (such as air combat) may employ mathematical representations of human operators as well as of the physical systems. These models are employed in the systematic study of the behaviour and capabilities of complex systems.

Human interactive domain:

- **Live**. A representation of military operations using military personnel and equipment which simulate experiences achieved during actual operational conditions. Live simulation participants perceive the environment via actual sensors or directly with their own eyes.
- **Virtual**. A simulation involving real people operating simulated systems. The human-in-the-loop in virtual simulations has a central role through the exercise of motor control skills (e.g., flying an aircraft), decision skills (e.g., committing fire control resources to action), or communication skills (e.g., as members of a C4I team).
- **Constructive**. Models and simulations that involve real people making inputs into a simulation that carries out those inputs by simulated people operating simulated systems. Wargames, models and analytical simulations that typically involve aggregated software representations of units, their behaviour and associated outcomes.

Hardware-in-the-loop domain: Simulations that involve actual hardware components of military systems (e.g., a missile seeker head) integrated with simulations of the other components of the overall system.

Simulation Based Acquisition. A process involving an integrated application of M&S that supports military systems from initial concept development through the acquisition phase to in-service support.

Synthetic Environment. Computer generated representation of the real world. Most often used to recreate a virtual battlefield in which simulations linked via networks can conduct and fight a highly realistic battle.

Development of Simulation Services to Support Military Experimentation

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19. ABSTRACT

One certainty for the future of warfare is change. To be prepared for tomorrow's new challenges, Defence requires organisational flexibility and innovation. A Joint Synthetic Environment (JSE) may facilitate this capacity for change and innovation across Defence. A JSE would link existing and emerging synthetic environments such virtual air, land and maritime platforms; C4ISR, EW and IO simulations developed in DSTO, industry and by our allies through the use of interoperable standards and simulation services based on High Level Architecture (HLA). The extension of the Experimental Command, Control, Communications and Intelligence Technology Environment (EXC3ITE) network to support the use of distributed simulation and military synthetic environments is examined from a corporate research perspective. Issues from operational, systems and technical perspectives are presented, addressing the use of emerging simulation middleware (eg HLA), in harmony with legacy simulation standards. Recommendations are made for progressing the development of simulation services, which will require a response from industry to develop as a National capability to underpin future military experimentation and innovation in Australia.

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